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This Issue Contains

NEWS ABOUT THE SOCIETY AND ITS COMMITTEES:

MISCELLANEOUS NEWS NOTES:

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ASTM BULLETIN

"Promotion of Knowledge of Materials of Engineering, and Standardization of Specifications and Methods of Testing"

TELEPHONE—Rittenhouse 6-5315

R. E. Hess, Editor
R. J. Painter, Associate Editor

CABLE ADDRESS—TESTING, Philadelphia

Number 164

FEBRUARY, 1950

Plans Under Way for 53rd Annual Meeting, Week of June 26

Apparatus and Photographic Exhibits Will Also Be in Atlantic City

During the entire week of June 26, the Society's Fifty-Third Annual Meeting will be under way in Atlantic City. In conjunction with this meeting will be the Ninth Exhibit of Testing Apparatus and Related Equipment, and the Society's Seventh Photographic Exhibit and Competition. Some information on these exhibits is given on the following page.

All members and committee members who possibly can should plan to get to Atlantic City sometime during the week.

Many important technical contributions are in course of development, and the April BULLETIN will give many more details. Some information on symposiums and sessions appears in the paragraphs which follow. The meeting will be notable among other things for the concentration of discussion on metals for use at elevated temperature service.

Entertainment and Social:

The Philadelphia District is again acting as host for the meeting, and will plan some social events for everyone including a specific program of ladies' entertainment. Based on the experience with the 1949 meeting, also at Atlantic City, the committee has plans under way for events that will be very interesting—further details later.

The Philadelphia District Council is holding monthly meetings from now on to complete its plans and to put into effect the various projects.

Technical Sessions:

Although plans are not complete, the following symposiums are scheduled for the technical sessions:

SYMPOSIUM ON EFFECT OF SIGMA PHASE ON THE PROPERTIES OF METALS AT ELEVATED TEMPERATURES, AND SYMPOSIUM ON CORROSION AND EROSION OF GAS TURBINE MATERIALS.—Sponsored by the Joint Committee on Effect of Temperature on the Properties of Metals.

SYMPOSIUM ON SAMPLING OF BULK MATERIALS.—Sponsored by Committee E-11 on Quality Control of Materials.

SYMPOSIUM ON THE ROLE OF NON-DESTRUCTIVE TESTING IN THE ECONOMICS OF PRODUCTION.—Sponsored by Committee E-7 on Non-Destructive Testing.

SYMPOSIUM ON METHODS OF TESTING SOILS UNDER TRIAXIAL LOADING AND SYMPOSIUM ON IDENTIFICATION AND CLASSIFICATION OF SOILS.—Sponsored by Committee D-18 on Soils for Engineering Purposes.

There will be other technical papers presented covering varied subjects of interest.

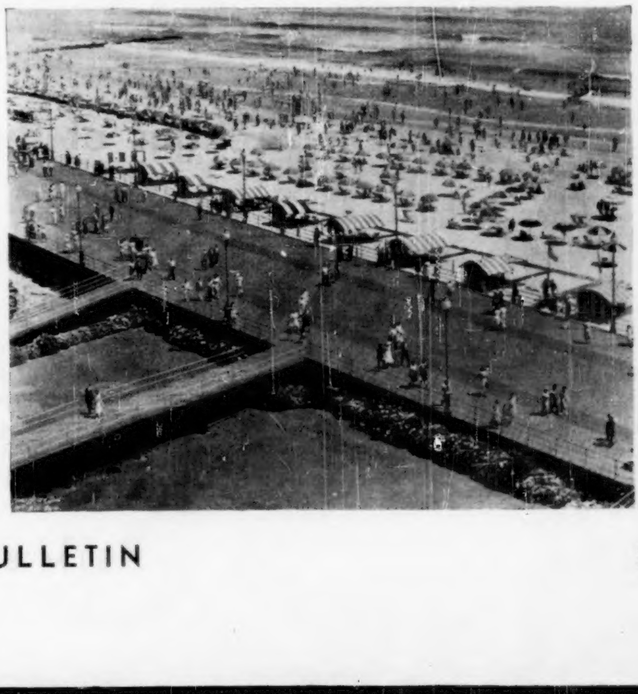
Marburg Lecture:

At the Annual Meeting this year, the Marburg Lecture will be presented by D. Wallace R. Brode, Associate Director of the National Bureau of Standards. He will speak on spectroscopy as allied to testing and analysis of materials.

Dr. Brode, formerly Professor of Chemistry, Ohio State University, is a member of A.S.T.M. Committee E-2 on Emission Spectroscopy and Chairman of the Committee on Application of Spectroscopy to Chemistry, National Research Council. He has recently accepted the temporary chairmanship to effect organization of the new Committee E-13 on Absorption Spectroscopy.

NOTE THE WEEK OF JUNE 26

Everyone who reads this note is urged to mark the week of June 26 on his calendar and plan to be in Atlantic City. Attendance at the technical sessions, exhibits, and other events will be amply justified.



The Sea, Sand, Boardwalk, Flowers and People at Atlantic City

Airview of Chalfonte-Haddon Hall, and Surrounding Area

Large Variety of New Testing and Scientific Instruments to Be Shown at 1950 Apparatus Exhibit at Atlantic City

Leading Companies to Participate

If there is one thing certain about the testing and evaluation of materials and advancement of research it is that progress is being made constantly. New and improved methods and procedures for evaluating materials and products are constantly being developed in A.S.T.M. and throughout industry, all of which calls for new and better instruments and apparatus. This fact is one of the reasons why every member who can should plan to spend some time at the 1950 Exhibit of Testing Apparatus and Related Equipment to be held during the week of the Annual Meeting at Chalfonte-Haddon Hall in Atlantic City June 26–30. Leading companies in the instrument and laboratory supply field are participating and will have much new equipment on display—many items for the first time.

During this week also, adjacent to the apparatus exhibit, will be the Society's Seventh Photographic Exhibit. This will feature outstanding prints relating to the general subject, "Materials, Testing and Research." A committee of men in the Philadelphia Area, headed by L. Drew Betz as chairman, is directing the photographic exhibit. A.S.T.M. technical committees are sponsoring various sections in this exhibit.

Apparatus Exhibit

The 1950 Exhibit of Testing Apparatus and Related Equipment is the ninth to be sponsored under A.S.T.M. auspices. From its inception, the theme has been a technical and scientific one with emphasis on new developments that will be of interest to the members and the large numbers of visitors at the exhibit. In past years, many new instruments and much equipment have been first demonstrated at these shows, and this will hold true for 1950. Testing machines of all kinds will be on display. There will be glassware and laboratory metalware lines and several companies will stress new types of electrical equipment for rapid chemical and physical measurements, including stress analysis and dynamic testing. It is believed that time spent in the exhibit will be well repaid. Exhibitors and their representatives, many being members, will be glad to furnish full information about their products on display as well as other lines and at the same time will solicit suggestions from exhibit visitors.

AN EXTENSIVE NEWS ACCOUNT OF A.S.T.M. COMMITTEE WEEK WILL APPEAR IN THE APRIL A.S.T.M. BULLETIN.

Recent Actions of the Standards Committee

Changes Effected in Wire, Oxychloride Cement, Rubber, Plastics, and Bituminous Materials Standards

During the months of December and January the Society's Administrative Committee on Standards approved new tentatives and changes on existing standards as shown in the accompanying table. Some notes on the individual items voted on appear below.

Wire:

Revision of Specifications for Zinc-Coated (Galvanized) Iron Telephone and Telegraph Live Wires (A 111 – 43) and the preparation of the new specifications for Zinc-Coated (Galvanized) High Tensile Steel Telephone and Telegraph Line Wire (A 326 – 50 T) were undertaken in order to keep pace with commercial developments. The advent of heavier weights of zinc coating and of relatively high strength low resistivity telephone wire made it desirable to cover the developments. In order to avoid confusion, the members of Committee A-5 on Corrosion of Iron and

Actions of A.S.T.M. Administrative Committee on Standards, January, February, 1950

New Tentatives

Methods of:
Sampling Oxychloride Compositions and Ingredients (C 239 – 49 T).
Sieve Analysis of Magnesium Oxychloride Compositions, Aggregates and Fillers (C 240 – 49 T).
Sieve Analysis of Plastic Calcined Magnesia (C 241 – 49 T).

Specifications for:
Zinc Coated (Galvanized) High Tensile Steel Telephone and Telegraph Line Wire (A 326 – 50 T).

Revision of Tentatives

Specifications for:
Nonrigid Vinyl Chloride Plastics (D 744 – 44 T).

Revision and Reversion to Tentative of Standards

Methods of:
Tension Testing of Vulcanized Rubber (D 412 – 41).

Specifications for:
Zinc-Coated (Galvanized) Iron Telephone and Telegraph Line Wire (A 111 – 43).

Tentative Revision of Standard

Method of:
Test for Penetration of Bituminous Materials (D 5 – 49).

Withdrawal

A.S.T.M. Air Chamber Thermometer (A.S.T.M. Reid Vapor Pressure Test) (31*F*) from A.S.T.M. Spec. for Thermometers (E 1 – 49).

Steel believed that a separate specification for the high strength grade should be promulgated. The old "steel" grade is no longer being commercially specified and it has been deleted from the proposed revision of A 111 – 43. The word steel has been eliminated in the title of this specification.

The new tentative and revised A 111 will both appear in Part 1 of the new 1949 Book of A.S.T.M. Standards.

Magnesium Oxychloride:

Because approximately 50 million square feet of oxychloride cement flooring and marine decking are installed annually this is considered ample justification of the demand by architects, engineers, contractors, and testing laboratories that there be available accredited methods of test for the required materials. The Tentative Method for Sampling Oxychloride Compositions and Ingredients was developed by Committee C-2 on Magnesium Oxychloride and Oxysulfate Cement to meet this demand. Companion specifications, Tentative Methods for Sieve Analysis of Magnesium Oxychloride Compositions, Aggregates, and Fillers, and Tentative Method for Sieve Analysis of Plastic Calcined Magnesia, were also promulgated.

These will appear in Part 3 of the new Book of Standards.

Bituminous Materials:

The tentative revision of Standard Method of Test for Penetration of Bituminous Material (D 5 – 49), in brief when adopted, will restore the minimum time for the sample to be in the constant-temperature bath to that time in the original standard D 5 – 25. In addition it allows a range of one-half hour, so that the time of immersion is to be from 1 to $1\frac{1}{2}$ hr.

Rubber:

Standard Methods of Tension Testing of Vulcanized Rubber (D 412 – 41) have not been changed since the advent of the synthetic rubbers. Much investigation and refinement for obtaining better reproducibility of tension testing was done in connection with the Government's synthetic program. To modernize the methods, in this revision these improvements were included, but because further revision is contemplated and to avoid delay, the standard was reverted to tentative.

Vinyl Chloride Plastics:

Since nonrigid plastics are being used extensively for floor covering, decorating purposes, and insulation material, it has been found necessary to revise Specifications for Nonrigid Vinyl Chloride Plastics. The technology of these materials is still changing today and the Tentative consequently is being revised even though work is still progressing in Committee D-20 on Plastics.

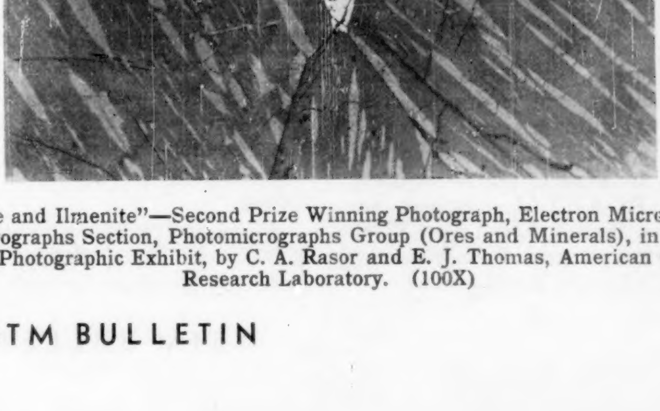
Thermometers:

The thermometer subcommittee of Committee E-1 believed it was not necessary to retain the A.S.T.M. air chamber thermometer (A.S.T.M. Reid Vapor Pressure Test Thermometer—31*F*.) as a standard thermometer since there are several available standard thermometers that are quite satisfactory for this particular use. The requirements for this thermometer have accordingly been incorporated in the vapor pressure method (D 323) by Committee D 2, which committee is also agreeable to discontinuing specifying the use of Thermometer 31*F*.

Committee on Cement Declares Airalon Acceptable

In keeping with the policy of the Society and its Committee C-1 on Cement, it is announced that the material known as "Airalon" has been declared acceptable as an addition to the cements covered in Tentative Specifications C 175 T and C 205 T.

The recognition comes after completion of suitable tests and review of existing data by the committee. The present specifications mentioned above will include, in their next revision, footnote reference to this latest addition to portland cement. The material is known commercially as Airalon, manufactured by the Dewey & Almy Chemical Co., and consists substantially of hydroaromatic and fatty carboxylic acids, being derived from an alkaline process of paper manufacture and neutralized to make a water-soluble soap. The acids, if regenerated from the soap, have an acid number of 150 to 160



"Hematite and Ilmenite"—Second Prize Winning Photograph, Electron Micrograph and Photomicrographs Section, Photomicrographs Group (Ores and Minerals), in the Sixth A.S.T.M. Photographic Exhibit, by C. A. Rasor and E. J. Thomas, American Cyanamid Research Laboratory. (100X)

New Publications

In the past few weeks some new compilations, manuals, and several parts of the 1949 Book of A.S.T.M. Standards have been made available. In addition to the 1949 Marburg Lecture on Residual Stresses in Metals by William Marsh Baldwin, Jr., the Symposium on Metallography in Color, and the Symposium on Effects of Low Temperatures on the Properties of Materials, all of which have been fully described in previous BULLETINS, some notes about the 1949 *Proceedings*, the Flat-rolled Steel Compilation, the Manual on Fatigue Testing, Special Compilations, and other items appear below.

1949 Book of A.S.T.M. Standards—Progress Report

With more than one-half of a monumental task completed the Society is pleased to announce that Parts 2, 4, and 5 of the new 1949 Book of A.S.T.M. Standards have become available during these past weeks and are being shipped to members in accordance with instructions on file.

Actually the whole job is nearer completion than it first appears. Part 1 will be finished at the printers as this BULLETIN goes to press, and the other two Parts, 3 and 6, soon will be ready for the printer; work on both of these has been progressing along parallel lines. Because of this, Parts 3 and 6 should appear in final form simultaneously sometime in March.

Today, with the extension of Society work into new fields, the complete Book comprises about 8300 pages with over 1580 A.S.T.M. Standards and Tentatives. To publish these in books of convenient size it was necessary to publish the complete 1949 Book in six parts:

Part 1 (On Press)—Ferrous Metals
Part 2 (Now Available)—Non-Ferrous Metals
Part 3 (March, 1950)—Cement, Refractories, Glass, Thermal Insulation, Concrete, Road Materials, Waterproofing, Soils
Part 4 (Now Available)—Paint, Naval Stores, Wood, Adhesives, Paper, Shipping Containers, Building Construction, Fire Tests
Part 5 (Now Available)—Textiles, Soap, Fuel, Petroleum, Aromatic Hydrocarbons, Water
Part 6 (March, 1950)—Electrical Insulation, Rubber, Plastics

Each Part has a detailed index with two convenient Tables of Contents, one listed by general materials, the other by numeric sequence of serial designations. The 1949 Book is bound in durable cloth with red backstraps trimmed in gold.

Parts 1, 5, and 6 are $10 each; Parts 2, 3, and 4 are $8 each; and all six parts are $54. To A.S.T.M. members for extra copies, Parts 1, 5, and 6 are $7.50 each; Parts 2, 3, and 4 are $6 each; and all six parts are $40.50.

Manual on Fatigue Testing

The Manual on Fatigue Testing, prepared by Committee E-9 on Fatigue, is now in print. The purpose of the Manual is to supply information to those setting up new laboratory facilities, to aid in operating the equipment properly, and to offer advice on presentation and interpretation of data.

The section on Symbols and Nomenclature for Fatigue Testing defines all terms (and their corresponding symbols) that are likely to be found in fatigue testing. The symbols used are those recommended by the American Standards Association.

The section on Fatigue Testing Machines classifies them as to (1) type of load, (2) type of stress, (3) design characteristics, and (4) operating characteristics. More than 30 illustrations aid in showing the differences in the various types of fatigue testing machines, as well as those used by many pioneers in the fatigue field, such as Moore, Krouse, Purdue, Sonntag, Schenck, Amsler, and others. This section contains more than 120 references.

The section on Specimens and Their Preparation presents information on various types of specimens, both metallic and nonmetallic, with detailed instructions for polishing them.

The Test Procedure and Technique section discusses such things as planning tests, selection of fatigue machines, selection of samples and preparation, and measuring specimens. The presentation and interpretation of fatigue data are summarized in two separate sections which describe general considerations in presentation and interpretation of data obtained from three different types of tests designated as material type, structural type, and actual-service type.

This 82-page Manual concludes with a bibliography which contains more than fifty references, although not intended to be complete on the subject of fatigue testing.

Copies of STP 91 can be obtained for $2.50 (cloth cover, $3.15); Members price is $1.85 ($2.50 for cloth cover).

Compilation of Specification for Steel Flat Products

Committee A-1 on Steel is sponsoring a new publication titled "A.S.T.M. Specifications for Steel Flat Products," intended primarily to present in a convenient form for reference the various A.S.T.M. specifications pertaining to steel plate, sheet, and strip materials.

It includes specifications for steel flat products for structural purposes and for boilers and pressure vessels prepared by Committee A-1 on Steel; also specifications for corrosion-resisting steel flat products developed by Committee A-10 on Iron-Chromium, Iron-Chromium-Nickel and Related Alloys. To make the volume more complete there are also specifications for wrought iron plate and sheet, prepared by Committee A-2 on Wrought Iron, and for metallic coated iron and steel sheets, under the jurisdiction of Committee A-5 on Corrosion of Iron and Steel.

Many of the specifications in this compilation are incorporated in the A.S.M.E. Boiler Construction Code and the specifications for structural purposes have widespread individual use.

The publication comprises approximately 200 pages and is expected to be available during March, 1950. The price will be $2.25 list, and $1.75 to A.S.T.M. members.

1949 Proceedings Aggregate 1200 Pages

The 1200-page *Proceedings* for 1949, Vol. 49, which include all of the reports of the technical committees and a large number of technical papers, will go in the mails shortly. This book represents one of the very tangible and important assets of membership in A.S.T.M. It is sent to every member, whether individual, company, or sustaining.

The difficulty of reviewing adequately

a 1200-page book is obvious, but some special material should be noted. One notable part is the Edgar Marburg Lecture on "Residual Stresses in Metals" by Prof. W. M. Baldwin. There are numerous technical papers in the field of ferrous and non-ferrous metals, and several dealing with cement, soils, plastics, and other subjects in which members are vitally interested.

The first 500 pages of the volume are devoted to committee reports including that of the Board of Directors, and its Administrative Committees. Several reports have technical appendices, for example—discussion on the effect of weather on the initial corrosion rate of sheet zinc; cooperative tests on relationship of strength of mortar to that of concrete; surface preparation and repainting of structural steel; and others.

Most of the technical papers were preprinted for distribution prior to their presentation at the Annual Meeting so that many members have seen these papers in that form, but a number were not preprinted, as follows: Effects of Temperature and Material Structure on the Fracture Properties of Medium-Carbon Steel, by Julius Miklowitz; Dynamic Creep and Creep Rupture Properties of Temperature-Resistance Materials Under Tensile Fatigue Stress, by B. J. Lazan; Long Time Tests of Concrete Containing Cements of Types I, II, and III Under Various Storage Conditions, by W. J. McCoy and S. B. Helms.

Discussion

One of the important features of the *Proceedings* is the discussion of the papers and sometimes reports. These discussions by various authors frequently bring out much additional information not given by the author, and sometimes they present additional supporting evidence, or, as frequently is the case, they may include a word of caution on certain interpretations.

To facilitate easy reference to subjects, there is a detailed subject index and an index of authors. Bound in dark blue cloth, this *Proceedings* follows the same style of previous years.

Special Groupings of A.S.T.M. Standards

Structural Steel, Magnetic Materials, Portland Cement Analysis, Concrete Units, Textile Definitions, Thermometers.

The Society has issued smaller compilations of A.S.T.M. Standards in the form of pamphlets which include only a limited number of standards in a very restricted field—structural steel, for instance, in the over-all materials field of ferrous metals. Descriptions of some of these special printings is given below.

Rolled Structural Steel.—Structural engineers, purchasing agents, producers, and others who operate within the field of rolled structural steel should find these 34 pages of 10 standards handy for ready reference.

The included specifications are for (1) general delivery requirements for structural rolled-steel plates, shapes, and bars; (2) bridge, building, silicon, locomotive, ship, rivet, high-strength rivet, and low-alloy structural steels; (3) low and intermediate tensile strength carbon-steel structural plates; and (4) low and intermediate tensile strength carbon-silicon steel for machine parts and general construction.

Saddle-stitched and punched, the "A.S.T.M. Specifications for Rolled Structural Steel" sells for $1.00.

Magnetic Materials.—This collection of seven standards (54 pages) is convenient for builders and users of electrical apparatus which incorporates steel in its design, the steel producer, research institutions, consulting engineers, and standardizing groups. Specifically, included are general methods for testing magnetic materials; definitions and terms; tests for normal induction, permeability, hysteresis, a-c. core loss and permeability of feebly magnetic materials; general tests for electrical and mechanical properties of magnetic materials; and general specifications for flat-rolled electrical steel. "A.S.T.M. Standards on Magnetic Materials" is priced at $1.00.

Portland Cement—Chemical Analysis.—Standard and tentative methods of chemical analysis of portland cement and information on analytical balances and weights are bound together for the convenience of those in the cement industry who are interested mainly in the analytical chemistry of cements. There are 58 pages of "A.S.T.M. Methods of Chemical Analysis of Portland Cement" and its price is 50 cents.

Concrete Masonry Units.—Designed for the manufacturer of brick and tile products, slate or municipal highway and public works departments, civil engineers, chemical manufacturers, and others who use large quantities of masonry units, this grouping of six standards satisfies a specific group.

In addition to methods of sampling and testing masonry units in general, there are specifications for hollow load-bearing, hollow nonload-bearing, solid load-bearing and manhole and catch basin, concrete masonry units. Specifications for concrete building brick are also included.

The 13-page "A.S.T.M. Specifications for Concrete Masonry Units" sells for 75 cents.

Textile Definitions and Glossary.—Special meanings of terms used in the textile industry, a rather complete list of various man-made and natural fibers available in commercial quantities, a glossary of textile terms which aids in the intelligent use of the industry's language, definitions and photographs of textile defects and definitions of fabric terms, and a recommended yarn-construction practice are saddle-stitched together to provide a convenient means of promoting better understanding among the various groups associated with the textile industry as to its nomenclature and interpretations. "A.S.T.M. Definitions and Glossary of Terms Relating to Textile Materials" (38 pages, punched) is priced at 50 cents.

Thermometers.—Since the accurate measurement of temperature is frequently important in many A.S.T.M. methods concerned with all materials engineering fields, specifying, testing, and standardizing of suitable thermometers are of universal importance.

All these problems are answered in the 57-page "A.S.T.M. Standards on Thermometers." Sidewire-stitched and covered with heavy manila paper, the collection is 75 cents.

Reprint Available—Preparation of A.S.T.M. Papers

Members, especially committee officers and prospective authors of papers for possible A.S.T.M. publication, will be interested to know that the Society is offering separate reprints (free on request) of an article, "A.S.T.M. Papers—Their Preparation, Acceptance, and Publication," which appeared on page 38 in the January, 1950, ASTM Bulletin. The article by G. R. Gohn, R. C. Adams, and K. B. Woods was specially prepared for and printed on the authority of the Administrative Committee on Papers and Publications.

For those who would like a personal copy of this explanation of what the Society will publish, who can write it, how it should be written, who reviews it, and where it will appear in print, the article has been made available as a reprint.

ASTM Bulletin

FEBRUARY 1950

NO. 164

NINETEEN-SIXTEEN RACE STREET
PHILADELPHIA 3, PENNA.

Advantages of A.S.T.M. Membership

DURING the past year, our A.S.T.M. members have done a great deal of work to aid the A.S.T.M. Committee on Membership, which is a subcommittee of the Board of Directors.

There are various phases of the work, but those which have greatly impressed us are the contacts made by our members, largely through letters in telling prospective companies and individuals what our members think about the benefits of membership. The following excerpts from copies of many fine letters in the Membership Committee files at Headquarters point up various aspects of why A.S.T.M. membership may be advantageous. Note that these excerpts stress different phases of membership indicating that to one member standardization may be of paramount significance, to another the personal contacts, and to another keeping in touch with trends, etc.

Participation in Development of Specifications; Research:

"The A.S.T.M. is, as you probably know, recognized as the basic materials specification making body. Most state and many Federal specifications are derived from or based upon A.S.T.M. specifications.

"In so far as specifications themselves are concerned, information or current requirements can be often obtained from several sources. The A.S.T.M. member has several added advantages. He participates in the development of specifications, understands the basic reasons of various requirements, gets the viewpoints of both producer and consumer interests on the committees, and is able to influence and promote specifications that are usable by, and equitable for, all concerned. Also he has advance information as to the direction new specifications are going.

"As a member of the Administrative Committee on Research it has been a privilege to see the broad coverage in research accomplished by the Society, not alone through its own committees but also through its many connections with other research groups.

"The Society is a leader in promoting knowledge of the evaluation and application of engineering materials."

Frequent Contacts and Personal Development:

"It seems to me that one of the main benefits of A.S.T.M. is the personal contacts and discussions at the annual meetings and at the committee week meetings. These contacts, together with active participation in the work of subcommittees, are very stimulating and serve to keep one much better abreast of the latest development in testing methods and specifications than is possible in any other way. As a result one gains advanced information regarding developments in the fields of testing and specifications. Although the A.S.T.M. meetings are conducted in a very businesslike manner, they afford some opportunity for relaxation and the annual renewal of friendships has proved a great satisfaction to me. It is generally accepted that the work of the Society is essential to American industry and that its benefits extend to all phases of industry. It seems to me that all of us should lend support to an organization that is working for our benefit."

Keeping Up with the Times:

"Apart from being in a technical society of high standing, membership in A.S.T.M. is invaluable for the standards and specifications which it issues. Not only are these specifications made available to you but by joining the committee which represents your particular industry you have the opportunity to partake in the formulation of these specifications which affect you. This permits you to keep your ear to the ground and spot trends before they are otherwise apparent."

Business Advantages: Reception of Technical Papers:

"I would strongly urge you to present the advantages of membership in this Society to your management. I can truthfully say that it has been the most useful, in a business sense, of the Technical Societies to us. The standards published by the Society are generally used in industry. The committee meetings and discussion which lead to these standards are most informative and rank with the best of the technical sessions held by any society. Your presence at these committee sessions would not only be informative but would be useful to your business in helping to shape the standards in a most desirable way. The Society itself wishes to have the fullest possible representation of producer and consumer present at these discussions.

"In addition to this work of setting up the standards, the Society presents and publishes a great number of technical papers. This activity is necessary to make available the latest developments and thoughts on various subjects so that members will have information necessary to arrive at standards when the need for them may arise."

It is frequently said that the best asset of the many held by the membership committee is the A.S.T.M. members themselves. The efforts of our members to promote interest in the Society has been probably the most important single factor in a steady membership growth and the continued help of our current members will insure that the curve of new members continues upward.

Standards in Advertising

WE ARE pleased at the many references to specific A.S.T.M. standards in advertising and in sales promotion work.

We believe such references are to be encouraged for they serve to bring to the attention of the user a better knowledge of A.S.T.M. standards. Time, effort, and money are spent in developing specifications and tests which are based on extensive research work. To achieve maximum benefits from all of this, the standards should be applied as widely as possible and the type of reference noted contributes to this.

Recently we noticed in a leading business journal a full-page advertisement with picture of the product covered and in very large type the statement—MEETS ASTM SPECIFICATION A 305. The copy explained what the specification was and referred to the product and the company producing it. What went through the mind of each person seeing the ad we would not presume to answer. But it is to be assumed that each of the many thousands who did see the advertisement took for granted that "It must be a quality product." Of course, this is a primary reason for using A.S.T.M. specifications—the assurance that if the product complies it is at a very definite, satisfactory level of quality.

Perhaps our members and others concerned with our work might suggest to advertising and sales executives that appropriate reference to A.S.T.M. standards from time to time would have specific advantages.

Standards Spearhead Advances in Power and Valve Casting Industries

Another Case History

High-Temperature Creep Test Plays Important Role

The use of A.S.T.M. standards for spectacular engineering works such as a huge building or bridge or a mammoth concrete dam, while very important, may not be the *most* significant use of our standards. The great significance of standard test methods and specifications in spearheading research has been the subject of a series of articles in the BULLETIN. The series has dealt with relation of standards to research in such fields as gaseous fuels (January ASTM BULLETIN), paints and allied materials, knock testing of fuels, and others. Below is a brief description by a long-time A.S.T.M. member, who is an authority in his field, involving the use of materials for high temperature service.

The purpose of these articles is to highlight this facet of the use of standards which, it is believed, has not been fully considered and evaluated before. We are apt to think of test methods and specifications largely from the standpoint of insuring quality, expediting delivery, insuring reproducibility of products, etc. Unquestionably the use of standard test methods in research is of incalculable influence in the development of new and improved products in the research laboratory.

The writer of the case history below, John Bolton, Director of Metallurgical Research and Testing, The Lunkenheimer Co., is widely known for outstanding work in his field. A member of many A.S.T.M. technical committees, notably A-3 on Cast Iron, A-1 on Steel and its Subcommittee XXII on Valves, Fittings, and Piping for High Temperature Service, and Committee B-5 on Copper and Copper Alloys, he also has for many years been active in the work of the Joint A.S.T.M.-A.S.M.E. Committee on the Effect of Temperature on the Properties of Metals. He was for a number of years secretary of that committee. This case history, brought to the attention of the A.S.T.M. Committee on Developmental Activities, is from a field in which the Joint Committee and Subcommittee XXII of A-1 have done pioneering work. Mr. Bolton is a member of the A.S.T.M. Administrative Committee on Research, and a contribution to a recent nontechnical activity has been his service as chairman *pro tem* of the Ohio Valley District, recently formally organized.

Research on Materials for High-Temperature Service

By J. W. Bolton

Although the Society does not include test requirements for elevated temperature properties of metals in its specifications, it has made available some recommended test methods. Among these is E 22, Recommended Practice for Conducting Long-Time High-Temperature Tension Tests, first published in 1933 as an outgrowth of several years of cooperative study. Prior to that time there had been great variations in techniques, and, in some cases, quite unreliable test data had been provided the engineering public. In the studies mentioned, testing variables were ferreted out, and procedures for accurate testing were established. The 1941 revision was and is helpful toward even more accurate and reliable testing procedure.

At the time of the original studies in the Joint A.S.T.M.-A.S.M.E. Research Committee on the Effect of Temperature on the Properties of Metals, the central power stations used in industry were beginning to go to 900 F. operation, as contrasted to the 750 F. operation common say to about 1928–1929. Long time tensile strength or "creep strength" is of relatively little moment, designwise, up to about 750 F., since useful working stresses at that temperature need be but slightly less than those applicable at room temperature. As temperature is increased, however, the drop in safely usable working stresses becomes increasingly rapid, up to and including operating temperatures of 1050 F. In some stations placed in operation within the last two years 2100 psi. steam is handled at 1050 F.

A.S.T.M. Recommended Practice E 22 is a test method without which development, evaluation, and applications of materials for safe usage under such conditions would have been impossible. Without this and other evaluative tests the cited advances in the power industry would have been impossible.

Similarly, in the cast-bronze alloys field the A.S.M.E. once proposed rating the alloy for steam or bronze valve castings, A.S.T.M. Specification B 61 and A.S.M.E. Boiler Code Specification SB-61, at 406 F. This would have greatly restricted the applications of bronze valves. Evaluations by means provided under E 22 led to up-rating that alloy as suitable to 550 F.

From the preceding it is evident therefore that this Recommended Practice E 22 is among test procedures whose development within the Society has had far-reaching engineering and industrial significance. We here at The Lunkenheimer Company have been enabled to evaluate our new materials researches by test methods among which E 22 is important.

Calendar of Society Meetings

American Society for Testing Materials—Committee Week, February 27–March 3, Hotel William Penn, Pittsburgh, Pa.

SOCIETY OF PLASTICS INDUSTRY—Spring Conference, March 2–4, Hotel Del Coronado, San Diego, Calif.

INTER-SOCIETY COLOR COUNCIL—Annual Meeting, March 8, Hotel Statler, New York, N. Y.

AMERICAN RAILWAY ENGINEERING ASSOCIATION—Annual Meeting, March 14–16, Palmer House, Chicago, Ill.

STEEL FOUNDERS' SOCIETY OF AMERICA—Annual Meeting, March 21–22, Edgewater Beach Hotel, Chicago, Ill.

SOCIETY FOR APPLIED SPECTROSCOPY—April 4, 1950, Socony Vacuum Training Center, New York, N. Y. (Speaker: R. H. Bell, Chairman E-2 Subcommittee on Fundamental Methods).

AMERICAN CHEMICAL SOCIETY—National Meeting (Divided), March 26–30, Houston Tex.; April 9–13, Philadelphia, Pa.; April 16–20, Detroit, Mich.

AMERICAN SOCIETY OF MECHANICAL ENGINEERS—Spring Meeting, Week of April 10, Hotel Statler, Washington, D. C.

AMERICAN CERAMIC SOCIETY—52nd Annual Meeting, April 23–27, Hotel Statler, New York, N. Y.

AMERICAN FOUNDRYMEN'S SOCIETY—54th Annual Convention and Exhibit, May 8–12, Public Auditorium, Cleveland, Ohio.

American Society for Testing Materials—53rd Annual Meeting and 9th Exhibit of Testing Apparatus and Related Equipment, June 26–30, Hotel Chalfonte-Haddon Hall, Atlantic City, N. J.

For previous case histories of significance of A.S.T.M. standards in spearheading research see: September BULLETIN, p. 15, Knock Testing of Fuels; October BULLETIN, p. 13, Cathode Specifications; December BULLETIN, p. 19, Paint and Varnish; January BULLETIN, p. 19, Gaseous Fuels. See future ASTM BULLETINS for additional case histories from the files of the Developmental Committee.

Financial Highlights—Calendar Year 1949; Notes on 1950 Budget

While a detailed report of the financial operations of the Society during 1949 will be included as customary in the next Annual Report of the Board of Directors, some interesting highlights are here excerpted from the report submitted by the Executive Secretary to the Board at its meeting on January 17, 1950.

1949 Operating Receipts:

The accompanying table shows operating receipts for the past three calendar years. Receipts for 1949 were slightly under those for 1948, accounted for in part by there being no exhibit in 1949, and the fact that sales of the 1946 Book of Standards were naturally lower in the third than in the second year following publication. Also there were fewer compilations of standards issued. Advertising in the Bulletin was up sharply, due to the publication of 7 instead of 6 issues and an increase in advertising rates that became fully operative last year. Increase in receipts from dues reflects the net increase in Society membership, which was slightly over 2 per cent.

1949 Operating Disbursements:

Operating disbursements totaled about $491,000, which is an all-time high. As usual, publications and salaries together account for close to 80 per cent of all disbursements. Expenditures for publications were up over 1948, largely because a big share of the costs of the 1949 Book of Standards is being paid from 1949 income. There is also reflected in this figure some increase in costs of printing. The increase in salaries reflects increases in the salary scale effective during 1949, and an increase in the size of the staff from 50 to 53. The ratio of salary roll to total disbursements, namely 35.1 per cent, compares with an average for the past five years of 34.8.

The item of headquarters' occupancy, plus the portion of salaries chargeable to building management, is equivalent to rent, and amounts to about $2 per square foot. This compares with Philadelphia office rentals in downtown locations and for comparable facilities of $3 a square foot and up.

Favorable Operating Balance:

For 1949 there was a favorable operating balance of just over $11,000. Operating balances or deficits for the past four years are as follows:

1946	−$27 911
1947	− 2 333
1948	+ 61 127
1949	+ 11 177

Net Surplus:

The net surplus on December 31, 1949, was $219,235, which is about 45 per cent of current annual operating disbursements. It is the feeling of the Board of Directors that the Society's financial position would be much stronger if these net reserves were at least equal to one year's operations; in other words, that the ratio just mentioned should be at least 100 per cent. The Board is giving consideration to this problem.

The growth of Society activities in the past decade, coupled with the influence of greatly rising costs, is seen in the fact that in the last decade Society disbursements have approximately tripled. In this same period the net surplus has increased a slightly lesser percentage, approximately 2.7 times.

Charts:

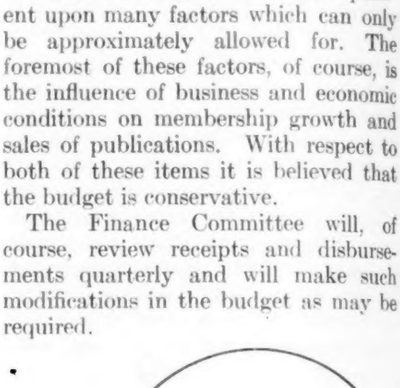
The charts here published give a graphic presentation of the source of the income dollar and how it was used. In the latter chart such expenses as salaries, general office expense, equivalent rent, and other overhead items have been apportioned to the major lines of activity shown in the chart.

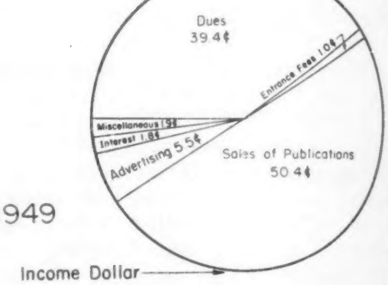
1950 Budget

In the budget for 1950, current income was placed at $560,000, made up of dues and entrance fees of $205,000, publication sales $301,000, miscellaneous items $54,000. Estimated disbursements are $550,000, made up of publication costs of $244,000; salaries including such expansion as required, $186,500; and general office expenses, committee and meeting expenses, and headquarters and miscellaneous $119,500. The budget for publications includes provision for publishing most of the papers presented at the Pacific Area National Meeting last October, as well as full provision for all regular and a number of special publications. It also includes the allotment of $40,000 of current income toward the reserve for publishing the 1952 Book of Standards.

It will be seen that a favorable operating balance of $10,000 is expected. Whether this will be realized is dependent upon many factors which can only be approximately allowed for. The foremost of these factors, of course, is the influence of business and economic conditions on membership growth and sales of publications. With respect to both of these items it is believed that the budget is conservative.

The Finance Committee will, of course, review receipts and disbursements quarterly and will make such modifications in the budget as may be required.





OPERATING RECEIPTS

Source	1949	Per Cent	1948	Per Cent	1947	Per Cent
Dues	$202 782	40.4	$199 892	38.6	$144 431	33.7
Sales of Publications	253 127	50.4	269 952	51.5	251 708	58.8
Miscellaneous						
Advertising	27 470	...	19 750	...	17 046	...
Interest and Dividends	8 849	...	6 991	...	6 968	...
Registration Fees	7 135	...	6 623	...	5 054	...
Exhibit	....	...	9 665	...	....	...
Total Miscellaneous	46 139	9.2	50 711	9.9	31 925	7.5
Total Receipts	$502 048	100	$520 555	100	$428 064	100

OPERATING DISBURSEMENTS

Item	1949	Per Cent	1948	Per Cent	1947	Per Cent
Publications	$205 080	41.8	$196 880	42.8	$195 617	45.4
Salaries	172 732	35.1	154 274	33.6	144 601	33.6
General Office Expense	42 124	8.6	40 910	8.9	33 925	7.9
Meetings and Technical and District Committees	28 291	5.8	26 890	5.8	21 545	5.0
Headquarters Occupancy	17 694	3.6	17 267	3.8	14 013	3.3
Miscellaneous, Including Retirement	24 950	5.1	23 206	5.1	20 696	4.8
Total Disbursements	$490 871	100	$459 427	100	$430 397	100

Student Prize Award Plan Renewed

Members Can Underwrite Student Membership as Prize

PRIOR to the war there was in effect at a number of technical and engineering schools a plan by which deserving students in engineering and science who had done outstanding work in certain classes would be awarded a student membership in the Society, the cost for this being underwriten by some A.S.T.M. member, frequently an alumnus of the particular school. It has been suggested that this plan, which became largely inoperative during the war, be publicized again. Full details of the plan are given in a special folder which will be sent to any member on request, but here, in essence, is the plan.

A member of the Society, by underwriting the cost of student memberships ($2 per year) can arrange to have these given to meritorious students as a recognition of their work or interest in certain courses which may tie in directly with A.S.T.M. activities. Usually the donor will set up the arrangements at the school of his choice with the dean of engineering or department head or professor. In the past, awards have been given for meritorious work in testing materials laboratory, courses in chemical engineering, and in courses involving mechanics of materials. The times at which the recipients are selected vary, depending upon the courses. Sometimes the student winners are advised by faculty members at the school or a letter is sent out directly from A.S.T.M. Headquarters.

It is believed that everyone concerned with this particular plan may derive considerable benefit. The student by his membership gets the ASTM BULLETIN, he may request the Year Book, can request reprints of technical papers and reports, and can procure a copy of special compilations of standards at greatly reduced prices, or the 300-page Selected Standards for Students without charge. For example, if he wants the compilation on petroleum, he may procure this at a charge of $2.25, compared with the list price of $5.50. In most cases the student price is about half the member's. The Society benefits by having the young student engineer or scientist become acquainted with its work, and he is a potential future member. Undoubtedly the school or department benefits by interest in the plan and from having meritorious students receive this rather simple yet distinctive recognition.

Yes, even the donor should get considerable satisfaction from supporting a plan of this kind, realizing that the benefits from it may be quite widespread.

Forms describing the award plan will be sent on request with no commitments implied. While there has been no uniformity in the number of awards underwritten by members, frequently five has been the number a member would sponsor but it has varied from three to ten. Should the donor wish Headquarters to make arrangements with a particular school rather than to handle the matter directly, this will be done gladly.

Pertinent Reading

"THE extension of standardization into fields not now covered—and there are several of these—should proceed in an orderly way. The great crying need today is not to rush forward into an accelerated program of creating new standards, but to accept in fact, not just in theory, the standards already on the books.

"It is difficult for an engineer to resist the urge to bargain for something special, something not quite standard, in order to achieve some local need, fancied or real. It is even more difficult for the manufacturer, in periods of low business activity to resist that request because not only does he need the business but also he does not wish to jeopardize the over-all and perhaps sizable order. The customer engineer, by winning from the manufacturer an agreement to something beyond the standard, may indeed take pride in this horse-trading, feeling he has achieved some gain for his company by so doing. Nothing is farther from the truth. The inescapable result is an increase in costs. They may be hidden costs, impossible to totalize, but they are none the less real. They inevitably must be taken into account and play a part in establishing cost levels all out of proportion to their transitory worth. In this respect, manufacturers are at the mercy of the users of their equipment. The power producers who are anxious to keep investment costs down must not only encourage the establishment of standards but also must insist that their engineers abide by them. The final users pay for every successful attempt to sabotage either a manufacturer's or an industry standard."

The closing paragraphs of an address by A. C. Monteith, Vice-President in Charge of Engineering and Research, Westinghouse Electric Corp., before the Annual Convention of the Edison Electric Institute, Atlantic City, June 1, 1949. An adaptation of this article was published in Standards World, *Autumn, 1949, entitled "Standardization—An Investment."*

A.S.T.M. specifications have an important place in covering materials which go into a modern central station unit, such as the one shown here. It is the Sewaren Station of the Public Service Electric & Gas Co. of New Jersey. In the foreground is a Westinghouse 105,000 kw. 1050 F. inlet steam temperature, 3600 rpm. tandem unit, with a similar General Electric unit in the background. Note the group of figures at the left to gain a concept of size.

Some of the construction materials used in those turbines for which A.S.T.M. has issued standards include steel plates, various types of pipe and tubes, the condenser tubes and plates, requirements for turbine rotors, generator shafts, etc., and other materials. The representatives of the power industry have contributed immeasurably to the advancement of the Society's work in standardization and research.

District Activities

Over 500 at Philadelphia District Meeting on Stress Analysis

A HEAVY attendance of over 500 greeted William T. Bean, Jr., Research Consultant on Stress Analysis when he gave his dynamic lecture in Philadelphia at the Benjamin Franklin Hotel on January 31. There was excellent representation from the A.S.T.M. members in the district, from A.S.T.M. Committee A-1 on Steel which held its meetings over the three-day period beginning January 30, and many members of the Society for Experimental Stress Analysis were present also. The meeting was a joint one sponsored by the A.S.T.M. District and the Philadelphia Section of S.E.S.A. At the dinner preceding the technical session with about 180 present, District Chairman A. O. Schaefer introduced the officers of both societies and called upon A.S.T.M. President J. G. Morrow, who spoke briefly complimenting the district for its active program. Mr. Bean was introduced by another live-wire individual, F. G. Tatnall, who had developed the program.

In his lecture which involved actual demonstrations of a great deal of equipment, some of it new, Mr. Bean repeatedly emphasized that available stress-analysis equipment and materials can almost always do a better and faster job of determining stress distribution than can an analyst with any kind of mathematics. Even a brief résumé of his talk is virtually impossible because of the extensive ground covered, but he kept the attention of everyone present from the very beginning to the close.

Mr. Bean is to give a somewhat similar lecture in St. Louis at a joint meeting of that District with the Engineers' Club of St. Louis. Anyone who can attend will be brought up to date on the latest equipment for stress analysis and related problems.

Several District Meetings Scheduled

Air Pollution, Electronics, Stress Analysis, Industrial Photography

A NUMBER of the districts are planning local meetings, some in conjunction with other society chapters and sections. Following its very successful meeting on Stress Analysis in Philadelphia, this district plans to have another technical session at the Franklin Institute on March 8 on the subject of Air Pollution. The New York District on March 24 will have an outstanding speaker on Electronics Research in Relation to National Defense. This is scheduled at the Engineering Societies Building.

On March 28 at the St. Louis Engineers' Club, the district there will hear Wm. T. Bean on Stress Analysis in Action, and on the following evening, March 29, in the Western Society of Engineers' auditorium, Chicago, will sponsor a meeting on Photography in Industry.

The New England District is planning a meeting on April 10, and the Western New York-Ontario group also is planning to have a session, possibly in St. Catharines that same month on April 21.

ALL MEMBERS ARE CORDIALLY invited to attend any of the meetings sponsored by districts. Direct mail notices go to the members and committee members in the respective areas, but their friends and associates are cordially invited also.

Philadelphia, March 8—Air Pollution

One of the country's outstanding authorities on air and stream pollution will speak at the March 8 meeting in Philadelphia at the Franklin Institute. Dr. Louis C. McCabe, Chief, Office of Air and Stream Pollution, U. S. Bureau of Mines, will cover the subject "Atmospheric Pollution." Prior to the technical session, the dinner speaker, W. B. Hart, Superintendent of Services, Atlantic Refining Co., will present the basic problem of atmospheric pollution and note some aspects, particularly the pressure to abate it.

A prominent geologist, Dr. McCabe was for three years Chief of Utilities Section and Deputy Power Procurement Officer in the Quartermaster General's Office of the U. S. Army. In 1944 he became a Colonel and had much to do with expediting mining of coal in Belgium and the recaptured European coal areas. He was director of the Los Angeles County Air Pollution Control District and then returned to the Bureau of Mines in 1949 in his present position.

A feature of this meeting will be the introduction of Dr. McCabe by his associate, A.S.T.M. Past-President and Honorary Member Dr. A. C. Fieldner, Chief, Fuels and Explosives Service, U. S. Bureau of Mines. Dr. Fieldner himself is an authority on this subject.

There is to be a dinner at the Institute's Dairy Dell beginning at 6:30 p.m. sharp. Reservations can be made through A.S.T.M. Headquarters.

New York, March 24—Electronics Research

The New York District is much interested in various aspects of research which are carried out by service branches of the Federal Government, and has been fortunate to secure as speaker at its March 24 meeting at the Engineering Societies Building, Edwin L. Speakman, who will cover the aspects of electronic research in relation to national defense. He is to be introduced by M. B. Chittick, formerly Colonel in the armed services and now head of the Reserve Officers in the New York District. This group is actively concerned with a number of technical problems.

While the subject of electronics research may from one viewpoint be rather special, it is believed the general principles involved, and the discussion which will follow the paper, will be of broad interest.

St. Louis, March 28—Stress Analysis

The St. Louis District in cooperation with the Engineers' Club of St. Louis, is sponsoring a joint meeting at the Engineers' Club on Tuesday, March 28, featuring a lecture by Wm. T. Bean, Jr., who gave a similar interesting demonstration in Philadelphia. This is a dynamic presentation and kept the close attention of over 500 men at the Philadelphia affair. The recent meetings held with the Engineers' Club have been very interesting and successful, and anyone attending this meeting it is believed will have spent a worth-while evening.

Chicago, March 29—Photography in Industry

Taking advantage of the fine new facilities of the Western Society of

Engineers, the Chicago District will feature at its meeting on March 29, the subject of Photography in Industry. The new Eastman film entitled "Functional Photography in Industry," an excellent over-all presentation, will be followed by a short technical talk and discussion by a technical representative of Eastman's Industrial Photographic Division in Chicago.

This meeting is to take the form of a President's night with the presence of the Society's chief executive, J. G. Morrow, Steel Company of Canada, Ltd., and Executive Secretary C. L. Warwick is joining him. Both will be called on at the meeting. This subject of photography is of widespread interest to many. Several fields where it is used are: metallography, spectroscopy, record keeping, etc. The sound color film of 35 minutes' duration gives a broad over-all concept of many important photographic functions.

New England—April 10—Sources of Power:

All A.S.T.M. members and committee members in New England are urged to attend the District Spring Meeting at Northeastern University on April 10, to feature an address on Sources of Power by Professor W. K. Lewis. This subject is of much interest to almost every technical man and is one of industry's widest concerns. Prof. Lewis is an accomplished speaker, and an authoritative and interesting discussion is in store.

There will be a dinner preceding the technical session, but arrangements have not been completed as yet. A notice is being mailed to all our New England members and others interested.

Western New York-Ontario—April 21—Photography in Industry:

The Western New York-Ontario District, under the Chairmanship of Dr. O. W. Ellis has arranged a joint meeting with the Niagara Peninsula Branch of the Engineering Institute of Canada to be held at the Hotel Queensway, St. Catherines, Ontario, on April 21. In connection with this meeting, the technical session of which will cover Photography in Industry, there will probably be some industrial plant visits. Final details are to be worked out and all members in that area will be posted. There are a number of places which would be of special interest to our members, including the Decew Falls Power Station and the Ontario Paper Company plant.

TECHNICAL COMMITTEE NOTES

Committee on Soaps To Meet

At the annual meeting of A.S.T.M. Committee D-12 on Soaps and Other Detergents, to be held at the Park Sheraton Hotel in New York City, March 21–22, several proposed new standards covering the testing and quality of various materials in the committee's scope will be considered and other activities will be reviewed.

The committee extends all interested in its work an invitation to attend the various subcommittee and main technical sessions.

A complete list of the meetings can be obtained from the Secretary, J. C. Harris, Monsanto Chemical Co., Nicholas Road, Dayton 7, Ohio. F. W. Smither, Chemist (Retired), National Bureau of Standards, Washington, is Chairman of the Committee, and Frederick Krassner, Department of the Navy, Brooklyn, is Vice-Chairman.

Over 30 standard specifications, tests, and series of definitions have been developed by the committee and published by the American Society for Testing Materials.

Committee D-12 has adopted the practice of concentrating its meetings in the spring and considers this its annual meeting.

Fatigue Questionnaire

Committee E-9 on Fatigue has appointed a subcommittee to survey the current status of research work in this country on fatigue of metals. This short but comprehensive questionnaire asks, in addition to the title of project and name of investigator, information on the length of project, purpose of the investigation, and methods employed, as well as results of fatigue studies published during the past year. The questionnaire also requests a listing of research topics or fatigue phenomena on which information is needed.

The primary objectives of this survey are (1) to prepare a list of all fatigue studies that are now in progress and (2) to list fatigue problems of a basic nature for which further information is desired.

These questionnaires have been mailed to 190 government, university, and industrial laboratories. The committee requests that those receiving these questionnaires cooperate as fully as possible so that the survey may be complete. If there are any members of the Society doing work in fatigue who have not received the questionnaire, they may obtain copies by writing to Headquarters or to T. J. Dolan, Research Professor of Theoretical and Applied Mechanics, University of Illinois, Urbana, Ill.

New Wax Committee Organizes

Organization of a new Committee on Floor Wax, recently authorized by the Board of Directors, is well under way. Dr. James I. Hoffman, National Bureau of Standards, has been appointed Temporary Chairman and Bayard Johnson, Franklin Research Co., Philadelphia, the Temporary Secretary.

Invitations are going forward to a group of industrial companies, institutions, technical associations, and consulting firms interested in floor wax to join in the work of this new committee. Within the next few weeks an organizational meeting will be held, after which a start can be made on some of the problems which have already been submitted.

These problems have been fairly well established and discussed in conferences, held under the auspices of the Floor Wax Division of the National Assn. of Insecticide and Disinfectant Manufacturers, who are vitally interested in the new committee. Before progress can be made with respect to the characteristics of floor wax, such as slip resistance and gloss, reliable standard methods of testing and means of evaluating these properties must be developed. For this reason, it is expected that the new committee will have this as its immediate objective.

Spring Meeting of A.S.T.M. Committee D-14 on Adhesives Scheduled

THE spring meeting of this Committee is to be held on March 27 and 28 at A.S.T.M. Headquarters, 1916 Race St., Philadelphia 3, Pa.

A cordial invitation is again extended to nonmembers to attend the two-day meeting. The fall meeting saw a large group of nonmembers in attendance who participated in the open discussion concerning the testing methods and procedures that are under study by the various subcommittees. It should be understood that the work of Committee D-14 embraces the entire field of adhesive applications and is not confined to a few adhesive types or any one segment of the industry. Come and bring your associates!

A departure from the usual meeting procedure will be undertaken at the spring meeting. Concurrent sessions of the various subcommittees will be held during the morning and afternoon of March 27. On Tuesday morning, March 28, the subcommittee reports will be presented, followed by the entire D-14 group meeting. Following luncheon, a paper will be presented by the guest speaker, Dr. Nicholas V. Poletika, Laboratory Superintendent, The Timber Engineering Co., Washington, D. C. Dr. Poletika will speak on Modern Adhesives Testing in the Factory and in the Laboratory. The report of Subcommittee VII on Research will be presented to the D-14 Committee to terminate the program.

Details concerning the meeting can be obtained from the Secretary of the Committee, G. W. Koehn, Research Laboratories, Armstrong Cork Co., Lancaster, Pa., or from A.S.T.M. Headquarters, 1916 Race St., Philadelphia 3, Pa.

Commtitee C-2 Expands Scope

MAGNESIUM oxysulfate cement has been in commercial use almost as long as magnesium oxychloride but the quantities marketed have been relatively small. More recently, magnesium oxysulfate cement compositions have been recommended as base coats under oxychloride cement ship-deck coverings. Similar compositions are coming into use as underlayments for prefabricated floor coverings. Oxysulfate plaster is also being promoted for walls in institutions such as mental hospitals where especially strong and durable wall covering is required.

With this increased use there has been a greater demand for standard methods of test and specifications. It is with this in mind that the scope of Committee C-2 on Magnesium Oxychloride Cement is being extended, by action of the Board of Directors, to include both magnesium oxychloride and oxysulfate cements.

Conference on Smooth Surface Organic Floor Coverings

FOR some time there have been inquiries received by the Society on the availability of standards in the field of smooth surface organic floor coverings, such as linoleums and asphalt, cork, rubber, plastic, and tile. Suggestions have been made that work be undertaken in this field. Producers and consumers were canvassed recently on the proposal that a new A.S.T.M. committee be organized for this purpose. As a result of the comments received, a conference will be held to review the work that such a committee should undertake, to crystallize the thinking concerning its establishment, and also to study its relation to other agencies on standards in this field. If it is apparent from the discussions that an A.S.T.M. committee should be organized, it is expected that the questions of scope, specific activities, and availability of suitable personnel will come up for consideration at the conference and recommendations formulated for submission to the Board of Directors.

The conference will be held at A.S.T.M. Headquarters on March 20 starting at 10 a.m. This will be under the chairmanship of G. E. Harnden, General Electric Co., a member of the Administrative Committee on Standards. Any member of the Society who is interested in this field and who has not received a letter of invitation is invited to attend this conference.

Work on Printing Inks

FURTHER progress in the technical program on the development of test methods for printing inks was made at a meeting of the Committee on Printing Inks (functioning under Committee D-1 on Paint Materials) held on November 3, at Atlantic City. Reports were received from seven subgroups on Definitions, Fineness of Grind, Rubproofness, Rheology, Paper Ink Relations, Drying Time, and Methods Review.

The Group on Fineness of Grind has made a survey of various methods in use as a basis for its future work. It has undertaken a study to evaluate two types of fineness of grind gages.

The work on rubproofness includes study of the Dryograph and also an examination of the scuff tester. This latter will include a study of the scuffing of the printing ink itself as well as the effect of rubbing the film on paper.

The Group on Printing Ink Rheology has prepared a preliminary definition of "tack" and has agreed on some general requirements for a practical instrument for evaluating tack. On this subject there are two working divisions, a midwestern section and an eastern section.

The Definitions Subgroup is cooperating very closely with other organizations in the graphic arts industry in arriving at definitions of terms of immediate interest in the printing ink field. A task group was appointed to prepare definitions covering varnishes which are needed in view of the wide range in viscosities of lithographic varnishes now available.

Officers of Committee E-4 on Metallography: L. to r. L. L. Wyman, Chairman; R. E. Penrod, Vice-Chairman; Mary Norton, Secretary

New Members to February 2, 1950

The following 75 members were elected from January 4, 1950, to February 2, 1950, making the total membership 6626.

Names are arranged alphabetically—company members first, then individuals.

Chicago District

GREAT LAKES CARBON CORP., Charles L. Thomas, Director of Research, 8210 Austin, Morton Grove, Ill.
KLEINSCHMIDT LABORATORIES, INC., Edward F. Kleinschmidt, Vice-President, 375 Roger Williams Ave., Highland Park, Ill.
DATH, GEORGE E., Chief Draftsman, W. H. Miner, Inc., 209 S. LaSalle, Chicago, Ill.
KELLY, G. ARNOLD, Chief Chemist, Marquette Cement Manufacturing Co., Oglesby, Ill.
KENNEY, JAMES B., Chief Metallurgist, Clark Equipment Co., Buchanan Plant, Buchanan, Mich.
MYLES, S. A., Plant Superintendent, Motive Equipment Manufacturers, Inc., 5253 W. Roosevelt Rd., Cicero 50, Ill. For mail: 1338 S. Kolin Ave., Chicago, Ill.
PHILLIPS, RICHARD L., Work Group Engineer, Soil Conservation Service, Council Bluffs, Iowa. [J]*
ULM, REIGN C., Assistant Manager, Research and Development Dept., Graver Tank and Manufacturing Co., Inc., 4809 Tod Ave., East Chicago, Ind.
WIEBE, RICHARD, Head, Motor Fuels Evaluation Div., Northern Regional Research Laboratory, U. S. Department of Agriculture, 825 N. University, Peoria, Ill.
ZELIFF, HARRY A., Plant Manager, Lehigh Portland Cement Co., Oglesby, Ill.

Cleveland District

BESSEMER LIMESTONE AND CEMENT CO., THE, Ralph E. Roscoe, Vice-President, 1100 Wick Bldg., Youngstown 3, Ohio.
CROSSAN, WILLIAM A., Vice-President and General Superintendent, Metropolitan Brick, Inc., 1017 Renkert Bldg., Canton 2, Ohio.
ROLIG, LYNN E., Development Chemist, Ohio Boxboard Co., Rittman, Ohio.

Detroit District

BUTTS, STEPHEN D., Engineer, O. W. Burke Co., 1032 Fisher Bldg., Detroit 2, Mich.
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SWEDISH STATE ROAD RESEARCH INST., Nils von Matern, Chief Engineer, Stockholm O, Sweden.
TREIBL, H. GEORGE, Chemist and Assayer, Luscar Coal's Corp., Luscar, Alta., Canada.

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* [J] denotes Junior Member.

PERSONALS • • •

News items concerning the activities of our members will be welcomed for inclusion in this column.

Note—These "Personals" are arranged in order of alphabetical sequence of the names. Frequently two or more members may be referred to in the same note, in which case the first one named is used as a key letter. It is believed that this arrangement will facilitate reference to the news about members.

Peter T. Baechinger, formerly associated with Stoffel & Co., Mels, St. Gallen, Switzerland, is now with St. Galler Feinwebereien A.-G., Lichtensteig, Switzerland.

Cecil E. Bales, formerly Vice-President, has been elected President of The Ironton Fire Brick Co., Ironton, Ohio. A Past-President of the American Ceramic Society, and a member of A.S.T.M. since 1926, Mr. Bales has been active in the work of Committee C-8 for over twenty years, serving as its Secretary 1932–1936. He was also a member for many years of Committee D-3 on Gaseous Fuels.

An outstanding honor was paid **T. A. Boyd,** Research Consultant, Research Laboratories Div., General Motors Corp., Detroit, Mich., and an A.S.T.M. Past-President, when he received the Horning Memorial Medal at the 1950 Annual Meeting of the Society of Automotive Engineers in Detroit. This Award was in recognition of Mr. Boyd's outstanding contributions during his 30-year study of fuels and engines. C. L. McCuen, General Manager of the GM's Research Division, said that "the study has benefited not only the motorist, by providing him with improved automotive engines, but also it has made a progressive impact on the economy at large by pointing the way toward more efficient utilization of hydrocarbon fuels." When he received the Award Mr. Boyd presented a very significant lecture entitled "Pathfinding in Fuels and Engines" which gave a very complete background of fuel and engine development. His many friends and associates in A.S.T.M. will join in extending hearty congratulations to him on this new honor.

H. V. Churchill, Chief of the Analytical Div., Aluminum Research Laboratories of the Aluminum Company of America, New Kensington, Pa., is serving as an official of Rotary International, world-wide service organization, for 1949–1950.

Harry Collyer, formerly in charge of the rubber and plastics testing and technical service at the Boston Research and Development Department of Godfrey L. Cabot, Inc., has been appointed Laboratory Director of Cabot Carbon, Ltd., Ellesmere Port, England, effective April 1, 1950.

Harold N. Cooledge, Jr., formerly Vice-President, F. J. Cooledge & Sons, Atlanta, Ga., is now President, Allied Paint Mfrs., of the same city.

Maurice W. Daugherty, formerly Chief, Cleveland Research Div., Aluminum Company of America, has been made Secretary, Aluminum Research Laboratories, New Kensington, Pa. In this newly created position he will assume some of the administrative functions of the Director's office.

Gustavus J. Esselen has been elected Vice-President of the United States Testing Co., Inc., Boston, Mass. He will continue in active direction of the Esselen Research Division, recently created by the merger of Esselen Research Corp. with the U. S. Testing Co.

S. S. Gill, formerly with Indian Steel & Wire Products, has been appointed Chief Metallurgist, Hindusthan Motors, Ltd. Uttar Para, India.

J. F. Magee, formerly Vice-President, is now President of Alpha Portland Cement Co., Easton, Pa.

Francis L. Mark, previously associated with Lancaster Processes, Inc., New York City, is now Sales Development Engineer, Dewey & Almy Chemical Co., Cambridge, Mass.

Robert W. Matlack, immediate Past-President of the Federation of Paint and Varnish Production Clubs, has been visiting in France, Switzerland, and England where he will inspect a number of industrial plants and laboratories, and will represent the organization at a meeting in Geneva of the newly formed Federation of Technical Associations of the Paint Industries of Continental Europe.

George S. Mikhalapov, formerly Manager, Air Reduction Sales Co., Murray Hill, N. J., is now Technical Director, Metallurgical Research & Development Co., Washington, D. C.

F. H. Nagel, Jr., for many years Secretary and Treasurer, Cann & Saul Steel Co., Philadelphia, Pa., has been named Vice-President of his company. Mr. Nagel has been representative of Cann & Saul membership in A.S.T.M. since 1937.

E. P. Newhard has been elected Vice-President, Pennsylvania-Dixie Cement Corp., Nazareth, Pa., at the same time continuing his duties as Operating Manager.

Alden Frederick Presler has concluded his graduate studies at the University of Minnesota, Minneapolis, and is now a Research Fellow, Iowa State College, Engineering Experiment Station, Ames.

Max Schuster, formerly Director, Quality Control and Development, Cantor-Greenspan Co., Inc., New York City, is now associated with the Quality Control & Production Div., Kanmak Textiles, Inc., of the same city.

Walter M. Scott, formerly Director, Southern Regional Research Lab., U. S. Bureau of Agricultural Chemistry & Engineering, New Orleans, La., is now Assistant Chief of the Bureau, at the Department of Agriculture headquarters, Washington, D. C.

Fred B. Seely, Professor and Head, Department of Theoretical and Applied Mechanics, University of Illinois, Urbana, was honored by The American Society of Mechanical Engineers with the Worcester Reed Warner Medal, given annually for outstanding contributions to permanent engineering literature. His citation noted that his textbooks "have had a profound influence on the development of young engineers for a quarter century." Prof. Seely joined the University of Illinois in 1909, and became department head in 1934. A member of A.S.T.M. since 1915, he has been active in the work of Committee E-1 on Methods of Testing for many years.

John C. Southard, Director of Research, Solar Aircraft Co., San Diego, Calif., has been appointed a member of the Subcommittee on Aircraft Structural Materials, a technical subcommittee of the National Advisory Committee for Aeronautics. Before joining Solar in 1946, Mr. Southard served with the U. S. Department of Agriculture, with the U. S. Bureau of Mines, and as Chief of Process Metallurgy Research, Titanium Alloy Manufacturing Co. Dr. Southard is a member of the Aviation Panel, A.S.T.M.-A.S.M.E. Joint Committee on Effect of Temperature on the Properties of Metals.

Hewitt Wilson, technologist and administrator associated with the U. S. Bureau of Mines since 1920, has been appointed Director of the Bureau's Southeast Region, with headquarters in Norris, Tenn., and including several stations and district offices in the States of Tennessee, North and South Carolina, Georgia, Alabama, Mississippi, and Florida. Mr. Wilson has been administrative head of the Norris station since its establishment in 1938 with a laboratory turned over to the Bureau by the Tennessee Valley Authority as its nucleus. Prior to his full-time appointment, in 1938, Mr. Wilson for 18 years had been on the faculty of the University of Washington as head of the Ceramics Department. He is the author of a textbook used by many ceramics schools in the United States. A member of A.S.T.M. since 1933, Mr. Wilson is active in Committees C-8 on Refractories and C-21 on Ceramic Whitewares.

James C. Zeder, Chairman of the Engineering Board at Chrysler Corp., Detroit, Mich., recently took office as the 1950 President of the Society of Automotive Engineers. Mr. Zeder became a member of S.A.E. in 1923 and served during World War II as Chairman of the S.A.E. War Engineering Board which headed extensive technical advisory projects to the United States and Allied armed services.

Preliminary Considerations for Testing Sandwich Radome Materials[1]

By G. R. Huisman[2] and R. H. Wight[2]

LARGE radomes used on present-day aircraft are conceived to satisfy several compromising design requirements which invariably lead to the use of a high-strength plastic sandwich structure. In the course of radome design, it becomes apparent that certain physical property values are needed for producing a satisfactory radome having adequate electronic characteristics and also sufficient strength. This is especially true of large radomes where structural considerations force a compromise of electronic considerations by dictating an increase in face thickness or over-all thickness.

Some time ago, radome designers in several aircraft companies on the West Coast began to compare mechanical test data and found some rather divergent and conflicting results especially from flexural tests. Several different size specimens were being used, each laboratory employed its own method for measuring face thickness (a basic item for computing stresses), and flexural strengths of very similar materials apparently ranged from 12,000 to 50,000 psi. It was obvious that much could be gained by a standardization of test procedures for evaluating X-band radome materials. Also, A.S.T.M. Committee C-19 was established on the premise that sandwich structures, having rather widespread acceptance in many fields, hold forth a good potential for future growth and, as such, present a group of essentially new materials wherein standardized testing procedures can be useful. The widespread adoption of sandwich structures, which on the one hand illustrates the need for some standardization, poses on the other hand to be the most serious obstacle to be overcome in accomplishing the purpose of this committee.

Radomes represent the most prevalent and recurrent application of sandwich structures in aircraft, although other uses varying from tables and partitions to primary structures are growing rapidly in some quarters. Because of this, standard test procedures for sandwich materials in general and for radome materials in particular are desired by the aircraft industry.

To be of practical use for comparison purposes and for correspondence between separate agencies concerned with similar problems, testing procedures must be standardized beyond theoretical concepts to contain specific values which are dependent upon and consistent with the class of material being tested. This is especially true of flexure tests where the testing procedure is influenced by so many variables from the modulus of elasticity of the faces to the cell size of the core.

Generally, X-band radomes consist of a sandwich structure with glass fabric base plastic faces varying in thickness from 0.030 to 0.010 in. and a lightweight core correspondingly varying from 0.300 to 0.450 in. with the over-all dimension varying therefore from 0.360 to 0.470 in. These configurations are normal sandwich structures, and it appears at first sight that classical testing procedures are applicable, but appreciable errors can accrue if the usual assumptions for flexure testing are made in interpreting test results. Although other tests are important, this paper will be limited to discussion of the flexure *testing* of X-band radome sandwich materials.

For apparent reasons, comparative testing procedures for composite materials should be conceived so that the effects of interaction are held to a practical minimum. For example, a high shear stress combined with high normal stresses in the core can precipitate a failure in a flexure specimen at an appreciably lower stress than the specimen would carry if the shear stress were reduced. Likewise, a core material will fail at a lower calculated shear stress if the faces of the sandwich were to impose combining stresses on it. For standardization purposes, therefore, interaction effects should be reduced to a practical minimum. Ultimately, interaction effects must be understood for a careful analysis of radome designs, but the approach now being used is to design conservatively and subsequently to static test a complete radome prior to use. It is obvious that more data are needed for the improved designs required by increasing demands for better performance. The present need for more complete design information can be satisfied by data obtained from tests which practically isolate individual physical characteristics and, therefore, eliminate interaction effects. This approach for establishing a flexural strength test procedure leads to the use of relatively large span-depth ratios in the range of 60:1.[3]

The several core materials being used for radomes vary in shear strength from as low as 100 psi. to 300 or 400 psi. This low strength range dictates the use of a large span-depth ratio. Whenever large span-depth ratios are employed, the deflections become rather great and in some cases have been measured at over 5 in. with a span of 30 in. It should be noted that the modulus of elasticity for the faces of sandwich radome materials is about 2.5 to 3.0 × 10^6 psi., or approximately one-fourth that of aluminum alloys. It is in these large deflections that we find the greatest significant difference between testing sandwich radome materials and testing ordinary monolithic materials. In the case of simply supported beams, large deflections with corresponding angular deflections at the points of support introduce horizontal end forces which have a significant effect on the stresses that exist in the specimen at failure.[4]

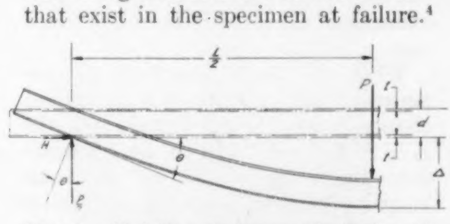

Fig. 1.—Relation Between Vertical and Horizontal Reactions.

This precludes ignoring these horizontal reactions or calculating stresses at failure with only vertical loads taken into account. Figure 1 illustrates the relation between vertical and horizontal reactions, and the bending moment at the center is seen to be

$$M = \frac{P}{4}\left[L + \tan\theta(2\Delta - d)\right]$$

and the maximum stress is calculated:

NOTE.—DISCUSSION OF THIS PAPER IS INVITED, either for publication or for the attention of the author. Address all communications to A.S.T.M. Headquarters, 1916 Race St., Philadelphia 3, Pa.

[1] This paper was presented at a meeting of Committee C-19 on Structural Sandwich Constructions held in San Francisco, Calif., October 13, 1949, during the First Pacific Area National Meeting of the Society.

[2] Chief Plastics Engineer and Research Analyst, respectively, North American Aviation, Inc., Los Angeles, Calif.

[3] Forest Products Laboratory Report No. 1556, revised October, 1948.

$$f = \frac{M}{bt(d - t)} + \frac{P \tan \theta}{4bt}$$

where:

M = bending moment,
P = load, at failure,
L = length,
Δ = maximum deflection,
d = depth of beam,
f = max. stress, at failure,
b = width,
t = thickness, and
θ = angular rotation at support.

This formula is based on the assumptions that the faces carry all axial bending loads and the stress in the face is uniform. These assumptions, while not strictly correct, are consistent with usual stress analysis and are considered satisfactory since the error introduced is essentially eliminated when the same assumptions are made for applying test data to design problems.

Ordinary flexural testing procedures indicate the following calculation for maximum bending moment:

$$M = \frac{PL}{4}$$

Making the same assumptions as noted above, as well as ignoring horizontal reactions, the maximum stress at failure is calculated:

$$f = \frac{M}{bt(d - t)}$$

To show the error introduced by the latter, consider a simply supported, 3-in. wide beam with 0.042-in. faces and 0.400-in. over-all thickness tested on a 30-in. span. The load at failure was 127 lb. and the deflection, Δ, at the center was 3.0 in. The angular rotation of the beam at the supports was 19 deg. According to the former method, the stress at failure was 22,600 psi. and according to the latter method 21,100 psi. or an error of 6.2 per cent. This example incidentally is not an extreme case.

Whenever high deflections are experienced in flexure tests, a significant change in span length can occur if the radii of the end supports are a reasonable percentage of the original span length. For some materials, this effect may be eliminated simply by reducing the radii of the supports. In the case of the subject materials, however, with their combination of thin faces and weak core, the use of such small radii would probably allow local crushing. Such crushing can be eliminated entirely by the use of suitable bearing plates between the small radius end supports and the sandwich specimens.

Stiffness factors can be obtained by testing beams of two different lengths wherein the shorter beam is the mid-section of the longer. In this way, variations of the material are not introduced into single sets of calculations. Deflection data should be limited, for obvious reasons, to values below the proportional limit, and for the longer 30-in. beam the data should be limited approximately to a 1-in. maximum deflection so that the horizontal reactions have little or no effect. One of the problems associated with determining stiffness factors to a reasonable degree of accuracy is that standard testing machines are usually not accurate in the range of load from 0 to 200 lb. A type "C" Tate-Emery air cell equipped with a portable, self-contained, two-dial Bourdon tube indicator for ranges of 40 and 200 lb. has been used with good results. Equipment of this nature is available commercially.

The width of specimen is a function of the type core material which is used. Large cell size materials such as honeycomb require a wide specimen to minimize edge effects. Erratic results obtained when too narrow a specimen of honeycomb core sandwich material is tested can be eliminated by using a 3-in. wide specimen, inasmuch as a $\frac{1}{4}$-in. cell size is the largest generally used in X-band sandwich radomes.

X-band radomes are most frequently molded under vacuum pressure applied by means of a flexible membrane "bag" placed over the assembly, sealed around its edges, and evacuated. When honeycomb or other large-cell core material is employed, this molding technique causes dimpling of the "bag"-molded face. Such dimpling and other irregularities make measurement of the finished face thickness difficult at best. Computation of stress values on the basis of unreliable face thickness measurements can lead to serious errors. Since the strength of a glass fabric base laminate depends mainly on the glass fabric employed, nominal face thickness values produce more useful results than most measured thicknesses. This is especially true when it is desired to compare results of two separate tests. A comparison of laminate thicknesses prepared by several aircraft companies was made with nominal values published by Owens-Corning Fiberglas Corp. It was seen that very little difference in thickness per ply existed. On this basis, the nominal values published by Owens-Corning are suggested for standard use.

With any material as inherently variable as a radome sandwich construction, a statistical approach in data analysis is desirable. The determination of the standard deviation and limits of averages in accordance with A.S.T.M. Manual on the Presentation of Data is extremely useful.[5]

There are other factors which apply generally to the testing of sandwich radome materials and which will only be mentioned here. Among these is conditioning of specimens which is particularly important in the case of foam type core materials. Standard conditioning for 48 hr. at 25 ± 1 C. (77 ± 2 F.) and 50 ± 2 per cent relative humidity is considered satisfactory. This is shown in A.S.T.M. Tentative Methods of Conditioning Plastics and Electrical Insulating Materials for Testing (D 618 – 49 T).[6] The orientation of fibers in the faces and the orientation of directional type core materials with respect to the test specimen depend on the purpose of the particular tests under consideration. Experience has shown that the most reproducible results are obtained with the face fibers running parallel and normal to the length of the specimen. With respect to this, it is questionable that tests conducted with fibers at an angle, say 45 deg., have much application. The orientation of directional type core materials in the specimen is quite important, especially when stiffness factors are desired.

Acknowledgment:

Acknowledgment for assistance is given to members of the Aircraft Research and Testing Committee of the Aircraft Industries Assn. W-25 Radome Mechanical Tests Subcommittee.

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[4] J. W. Westwater, "Flexure Testing of Plastic Materials," *Proceedings*, Am. Soc. Testing Mats., Vol. 49, p. 1092 (1949).

[5] A.S.T.M. Manual on Presentation of Data, Am. Soc. Testing Mats. (1940). (Issued as separate publication, *STP No. 15-B.*)

[6] 1949 Book of A.S.T.M. Standards, Part 6, p. 465.

Testing of Sandwich Constructions at the Forest Products Laboratory[1]

By Edward W. Kuenzi[2]

Evaluations of the properties of structural sandwich constructions and component materials have been carried on at the Forest Products Laboratory for nearly a decade. Much of this work has been done in cooperation with the ANC (Army-Navy-Civil) Technical Subcommittee on Wood Aircraft Structures and has been continued in cooperation with this group, now the ANC-23 Panel on Sandwich Construction of the Subcommittee on Air Force-Navy-Civil Aircraft Design Criteria, Aircraft Committee, National Military Establishment, Munitions Board.

During the early years of the recent World War, the Forest Products Laboratory had done intensive work on plywood, which led to the development of design criteria for the use of wood and plywood in aircraft. This work has been published as ANC *Bulletin 18*, "Design of Wood Aircraft Structures." Therefore, since sandwich constructions are likely to be orthotropic in nature, as are wood and plywood, it seemed logical to attempt to expand these design criteria to include sandwich constructions. Some of the testing procedures described in this paper are the results of studies made to check the conformance of sandwich constructions to these design criteria and are intended to simulate in so far as possible theoretical loading conditions or loading conditions that might prevail in service. Based on the results of these tests and their correlation with mathematical analyses, a bulletin on design criteria for sandwich constructions is now in preparation.

Additional studies to evaluate the suitability of sandwich constructions for other structures, such as housing, were also made at the Laboratory, and these test procedures will be outlined.

Some of the first sandwich constructions tested were composed of plywood facings bonded to balsa wood cores, the type of construction that was used in the British Mosquito bomber. Following these were sandwich constructions having papreg, aluminum, glass cloth, and steel facings combined with cores of balsa wood, pulpboard, cellular cellulose acetate, cellular hard rubber, corkboard, and cellular honeycomb cores of paper, cotton cloth, glass cloth, or aluminum foil. The purpose of testing such a wide range of materials was to be sure that the design criteria evolved would be correct for materials of extremely different mechanical properties. Mathematical analyses were derived for various structural elements, such as columns, beams, or panels, and tests were made to substantiate the theoretical calculations. The comparison of experimental results with the theoretical calculations led to design criteria.

A prime consideration was the behavior of flat or curved panels loaded in various ways. This, in turn, involved investigation of the stiffness of the sandwich in order to be able to determine panel stability under edgewise loads or the deflection of panels under transverse loads. Most sandwich constructions have relatively weak cores that allow appreciable deflection of the sandwich due to shearing deformations in the core. In order to calculate theoretically the buckling loads or deflections, it was necessary to know the properties of the component parts of the sandwich.

Testing of Facing and Core Materials

Stress-strain curves of the facing materials were obtained by testing samples of the facing material in compression. The modulus of elasticity could have been determined by a tension test, but knowledge of the behavior at compressive stresses greater than the proportional limit was needed to predict instability failures in compression. Therefore, the compression test was made, because behavior in compression was quite different than that in tension and was always the controlling mode of failure. Since the facings were thin, it was necessary that they be supported laterally during test to prevent buckling. This was done by lightly clamping the entire specimen, except for the very ends, between two I-shaped bars of steel $\frac{1}{2}$ in. thick. In addition, the specimen was dumbbell shaped to induce failure in the body of the specimen. The central 2 in. of specimen length were 1 in. wide and the ends were 2 in. wide, faired out by a radius so that the total length of the specimen was just 4 in. plus four times its thickness. Strains were measured over a 1-in. gage length at the central section by means of a Marten's mirror apparatus mounted on the edges of the specimen.

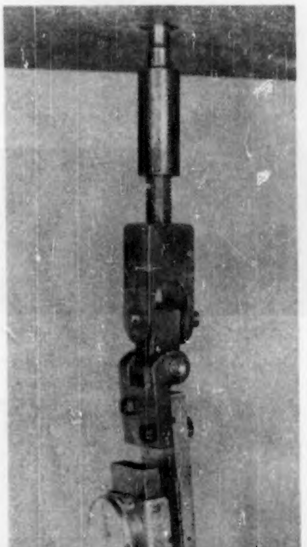

Fig. 1.—Shear Test of Core Material to Determine the Shear Modulus in Planes Perpendicular to Facings and Parallel to the Applied Force.

This test was also used to determine the shear strength of core materials.

Other properties of the facings, such as modulus of rigidity or Poisson's ratio, were known if the material was isotropic; if it was not isotropic, these properties were determined on thicker samples by methods similar to those used for core materials.

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[2] Engineer, Forest Products Laboratory, Forest Service, U. S. Department of Agriculture, Madison, Wis.

Required properties of the core material were the shear moduli, the moduli of elasticity, and the Poisson's ratios. Because most core materials are not isotropic, these properties had to be determined in three different directions.

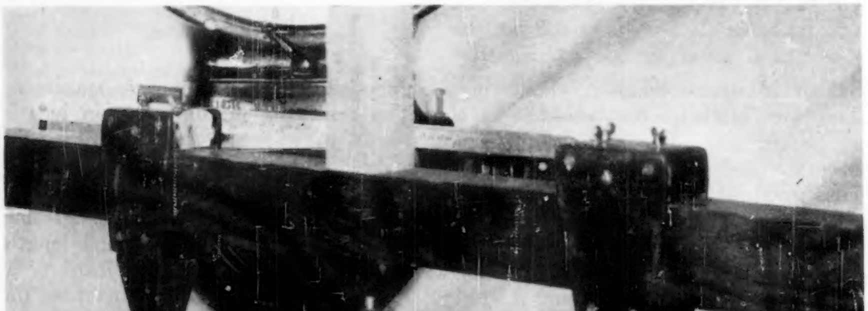

Fig. 2.—Test to Determine Shear Modulus of a Plate of Core Material.

The dial measures twice the deflections of the surface relative to the center of the plate.

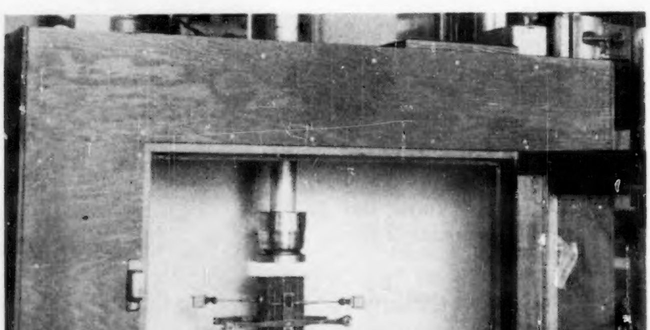

Fig. 3.—Compression Test of Core Material Showing Marten's Mirror Apparatus Being Used to Measure Strains.

The shear moduli were determined by several methods. The modulus in planes perpendicular to that of the facings and parallel to the direction of the applied force was obtained, together with shear strength, by bonding the core material between two steel plates, which were then loaded to induce shear in the core (Fig. 1). Deformations were measured by means of a dial gage attached to measure the motion of one plate with respect to the other. Alternately, deformations were measured by means of mirrors. One mirror was attached solidly to one of the loading plates, the other was mounted on two pins placed in the core in a plane normal to that of the facings. The relative rotation of this mirror with respect to the mirror mounted on the loading plate, as measured by means of a light beam and scale, gave the shearing deformations. The use of the mirrors eliminated the possibility of including slipping in the adhesive as part of the shearing deformation.

This modulus was also determined by flexure tests of specimens of sandwich construction. Identical or closely matched specimens were tested over two different spans. The shear modulus was determined by simultaneous solution of the deflection formulas, which included shear deformation terms.

Shear moduli associated with shearing strains in the plane of a plate of core material, or planes parallel thereto, were obtained by loading a square plate of the core material on opposite ends of one diagonal while supporting it at the other two corners, as shown in Fig. 2. For

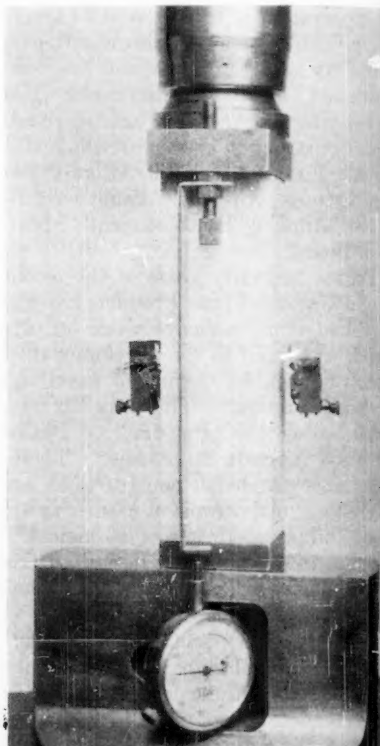

Fig. 4.—Compression Test of Core Material Showing Use of Tuckerman Gages Adapted to ¼-in. Gage Length.

orthotropic materials, any shear modulus can be determined by suitable orientation of the core material. The size of specimen was such that the ratio of length of side to thickness was not less than 20 nor greater than 40. The deflections of the resultant saddle-shaped surface at any load, conveniently measured by the apparatus shown in Fig. 2, were all that was needed to calculate the shear modulus.

A less accurate method of measuring shearing moduli, but one useful for preliminary investigations, is that in which the core material is used as a torsion pendulum. The modulus obtained is that associated with strains in the length-width plane of the specimen.

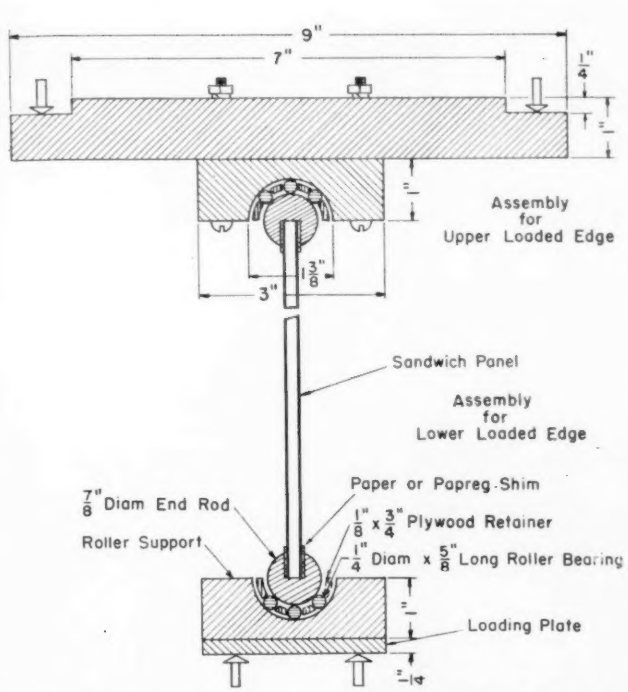

Fig. 5.—Sketch Showing the Details of the Fixtures by Which Simple Support of the Loaded Edges of Sandwich Panels Was Attained.

One end of a strip of rectangular cross-section is clamped and a suitable bob placed at the free end. The modulus is calculated from the period of vibration of the bob, which is determined by timing ten complete vibrations.

The moduli of elasticity were determined by placing a 2-in. square, 5- to 8-in. long, piece of the core material in compression. If such a specimen was not available, it was built up. If the core material was sturdy enough to support the apparatus, the deformations were measured with a Marten's mirror compressometer as shown in Fig. 3. For softer core materials, a Tuckerman gage was used to measure deformations. Figure 4 shows the Tuckerman gage adapted to a $\frac{1}{4}$-in. gage length, with the gage supported by small nails. This adaptation of the Tuckerman gage was also useful in determining the deformations in short specimens of core materials. These deformation-measuring devices fail to operate properly if the core material is so soft that it will not support the gage without creep occurring. In these cases, deformations were measured by observing high lights on small sharpened pins placed in the specimen. The distance between pins, in the same vertical plane, normal to the direction of loading, was measured by means of filar microscopes.

Poisson's ratios of the core material were measured by placing the specimens in a horizontal type of testing machine. The strains at several loads within the elastic limit, and in a direction parallel to the direction of loading, were measured with a Tuckerman gage. The load was then removed and the gage placed to measure strains at right angles to the direction of loading. The lateral strains were measured at the same loads used to measure the parallel strains, and Poisson's ratios were calculated as the ratio of the strains.

Tests of Aircraft Sandwich Constructions

Since aircraft structures are made up of various types of panels, flat or curved, and these panels are usually thin, it is essential to be able to predict the loads at which instability will occur or the deflections that certain transverse loads will produce in these panels.

Accordingly, flat panels of several sizes and constructions were tested in edgewise compression with different types of edge support. Simply supported edge conditions were approximated on the loaded edges by placing the panels in a series of short, slotted, round bars that were placed on small rollers, as shown in Fig. 5. Simply supported edge conditions at the sides of

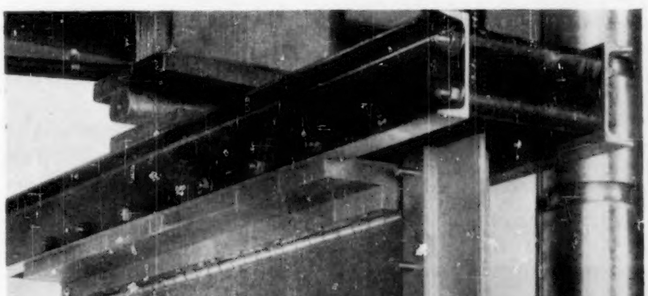

Fig. 6.—Test of a Flat Panel in Edgewise Compression.

All edges held to simulate simply supported edge conditions.

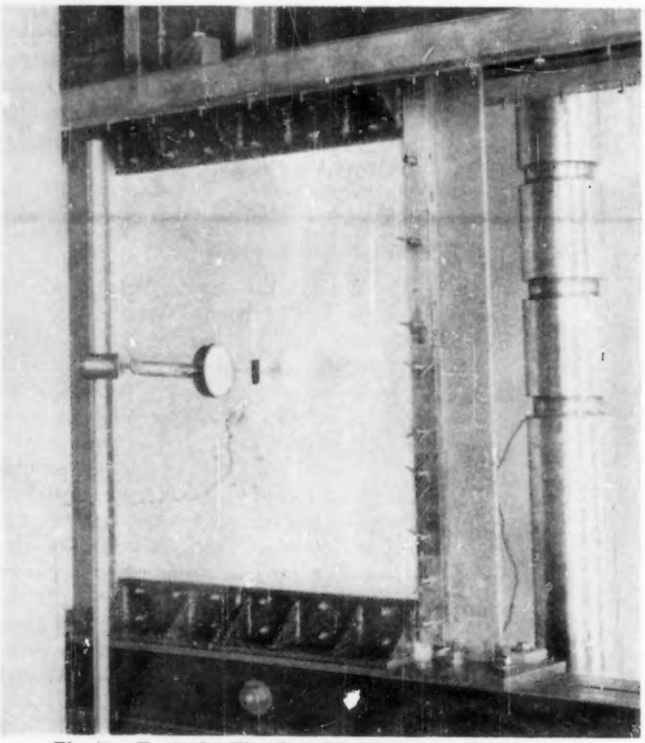

Fig. 7.—Test of a Flat Panel in Edgewise Compression.
Loaded edges are clamped and sides are simply supported.

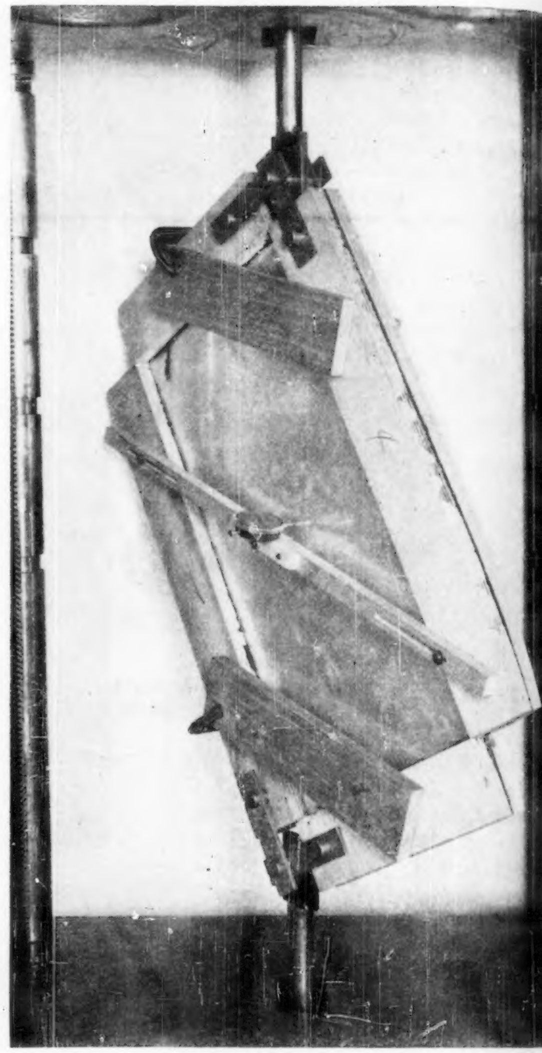

Fig. 8.—Test of a Panel of Sandwich Construction in Edgewise Shear.

the panel were obtained by supporting the panel between segments of narrow bars designed to hold the edges straight but adjustable for various panel thicknesses. Figure 6 shows a panel being tested under simply supported conditions at all edges. Electrical resistance strain gages were used to measure strains at various points in the panel, and dial gages were used to measure lateral deflections. The buckling loads were determined on the basis of the load-strain and load-deflection curves.

Clamped edge conditions at the sides of the panel were simulated by holding the sides between stiffened angle irons. Clamping of the loaded edges of the panel was approximated by bolting the ends of the panel between stiffened angle irons. A panel being tested with loaded edges clamped and remaining edges simply supported is shown in Fig. 7. Similar tests were made on flat panels having all edges clamped.

Flat panels were also tested in edgewise shear to determine their buckling characteristics. They were loaded through heavy plywood rails bonded to the panel at its edges. Shear was induced in the panel by pulling the framework diagonally through pins placed at the ends of the rails as shown in Fig. 8. Electrical resistance gages were used at

Fig. 9.—Sandwich Panel Before Assembly for Test in Combined Edgewise Shear and Compression.

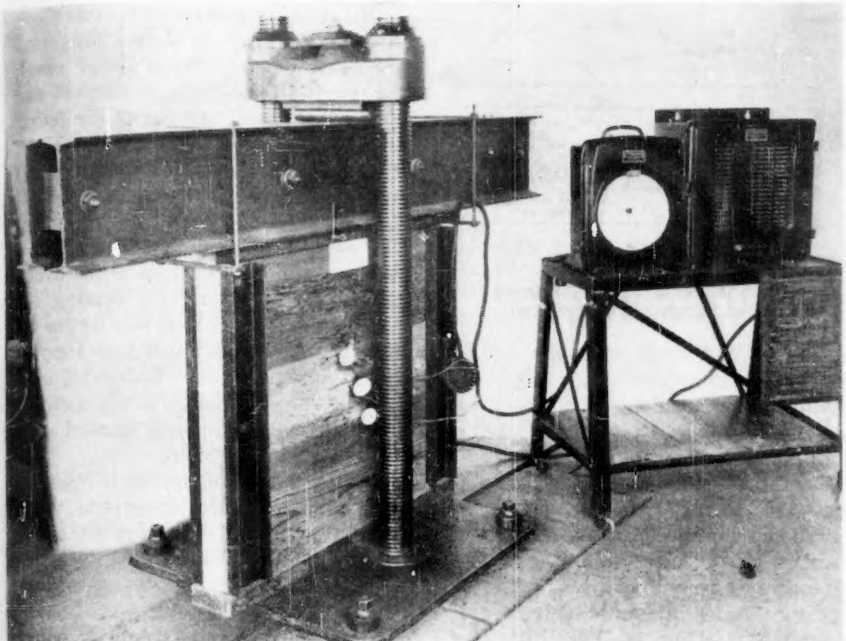

Fig. 10.—Testing Arrangement for Subjecting Panels of Sandwich Construction to Combined Edgewise Shear and Compressive Stress.

various points on several panels to determine the quality of the shear induced in the panel. Buckling loads were determined by observing the lateral deflection of the center of the panel.

Fig. 11.—Test of a Sandwich Construction to Determine the Wrinkling Behavior of the Facings Under Shear Stresses.

Combined edgewise shear and compression tests on flat panels were made by enclosing the panel in a heavy framework of wood glued to the panel. Figure 9 shows the panel before assembly. The proportion of shear to compression was controlled by placing the opening in the frame (which would be the size of panel actually being tested) at different angles to the direction of the applied load, which was always in compression parallel to the edges of the framework, as shown in Fig. 10. Strains used to determine the compression and shear applied were measured at different points on the panel by means of electrical resistance strain gages. The buckling of the panel was observed by measuring the lateral deflections with dial gages.

Uniform load tests, in a direction normal to the facings, were made on flat panels of sandwich constructions by placing the panels over an airtight, open-end box. The panel was held down at the corners with clamps. The edges were sealed airtight to the end of the box with strips of sponge rubber, but were left free to turn up as the load was applied, thus approximating the case of simply supported edges. A vacuum drawn inside the box provided the means for applying the load. The load was measured with a manometer. Deflections at the center of the panel were measured with a dial gage.

Curved panels of sandwich constructions were tested in axial compression. The panels were stiffened at the ends with an additional strip of thin aluminum or plywood bonded to each facing to prevent local compression failures. The edges of the panel were held straight in a shallow, loose-fitting groove cut into wood edge rails, which were shorter than the panel so that they would not carry any load. The upper end of the panel was brought to bear against the upper head of the testing machine, while the lower end rested on a flat plate supported by a large, spherical bearing. This plate was adjusted to bear uniformly on the specimen under a small initial load and was then held in place by jack screws placed at the corners of the plate. The load was applied until failure occurred. Electrical resistance strain gages were placed at several points across the width of some of the panels to check the distribution of load. The lateral deflections of the flatter panels were measured by means of dial gages. The buckling of panels curved to a smaller radius occurred suddenly and without previous lateral deflection, so that no lateral deflections were required to obtain the buckling load.

One of the possible modes of failure of sandwich construction, which applies to

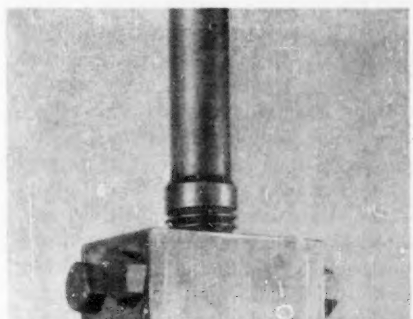

Fig. 12.—Test of Sandwich Construction in Tension Normal to the Facings, Used to Determine Strength of Facing-to-Core Bonds.

most structures, is wrinkling of the facings. The problem is similar to that of a column supported elastically throughout its length. Tests to check stresses at failures of this type were made by compressing a short column of the sandwich construction. If necessary, the ends of the facings were supported with small bar clamps or were cast in plaster or resin to prevent end failures at low loads. Strains in the facings were measured with electrical resistance-type strain gages. Theoretical considerations of this type of failure of sandwich showed that it is possible that small irregularities in the facings may cause early wrinkling failures. Therefore, the original profile of the irregularities in the facings was measured by traversing the specimen with an apparatus reading deflection to 0.0001 in. During the test of the specimen, the growth of these original irregularities was observed at increasing loads by means of an apparatus arranged to traverse the length of each facing. This apparatus consisted of one dial placed at each facing to read the deflections and another dial arranged to read the vertical position of the lateral dials as the traverse was made. The traverse was made rapidly, in about 5 sec., so that plastic flow effects were small, and the dials were photographed with a motion picture camera as the traverse was made. The readings of the dials were subsequently transcribed from the film. Tests of sandwich constructions conducted in this manner showed that the irregularities did grow and cause wrinkling failures at lower loads than formerly predicted.

The elastic stability of the facings of sandwich panels subjected to shear was measured by loading a small panel in a manner similar to that used to test the buckling of large flat panels in shear. Figure 11 shows the apparatus used to determine the wrinkling behavior of the facings.

Another factor that must be considered in the properties of sandwich constructions is the quality of the bond between the facings and the core. Since sandwich constructions must function as a unit, it is essential that this bond be good enough to meet this requirement. Various methods have been suggested for determining the quality of the bond. The method most often used at the Forest Products Laboratory was to test a 1-in. square sample of the sandwich in tension normal to the plane of the sandwich. The load was applied through aluminum cubes bonded to the facings of the sandwich. Figure 12 shows how the cubes were loaded through pins; the lower pin was placed at right angles to the upper pin, thus placing the specimen at the center of a

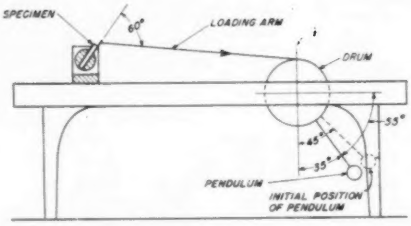

Fig. 13.—Diagrammatic Sketch Showing Method of Making Strip Test for Evaluating Quality of Bond Between Facing and Core of Sandwich Materials.

universal joint and avoiding eccentricities of load application.

Alternately, a method for measuring bond quality was to strip the facing from the core under impact load and to measure the energy required. This was done by placing the specimen in a special clamping fixture and pulling the facing from the core by means of the Laboratory's pendulum-type toughness machine. A diagrammatic sketch of the apparatus is shown in Fig. 13. The facing was pulled at an angle of 60 deg. measured from the plane of the sandwich. The position of the specimen in relation to the axis of rotation of the pendulum was adjusted so that the impact was delivered to the specimen when the pendulum was at an angle of 35 deg. from the vertical, and the pendulum bob was placed far enough from the axis of rotation so that the facing was stripped from the core throughout its entire length.

Of the many nondestructive methods used in attempts to detect unbonded areas in the completed sandwich panel, the one that was thought simplest and most reliable was tapping of the facing and listening for changes in sound of the tapping. Other methods tried were (1) special lighting to detect blisters, (2) supersonic inspection, (3) exposure of the panel to vacuum, (4) placing a vacuum cup over portions of the panel, (5) internal pressure, (6) heating the complete panel, (7) local heating, or (8) pulling on buttons bonded to the facings at various points. Unbonded areas were detected by many of the methods but the location of poorly bonded areas was not always possible.

The durability of sandwich constructions was measured in several ways. Qualitative tests of durability were made by exposing sandwich panels to actual and to artificial aging and weathering conditions.

The behavior of a sandwich under repeated loading conditions was determined by subjecting specimens of core material to fatigue tests in shear. The type of specimen was similar to that used to obtain shear strength and modulus (Fig. 1).

Fig. 14.—Apparatus for Applying Constant Load to a Shear Specimen of Sandwich Core Material for Observing Creep Characteristics.

Performance of sandwiches under constant load for long periods of time (creep test) was investigated by loading shear specimens of core materials to different percentages of maximum loads as determined from tests of matched

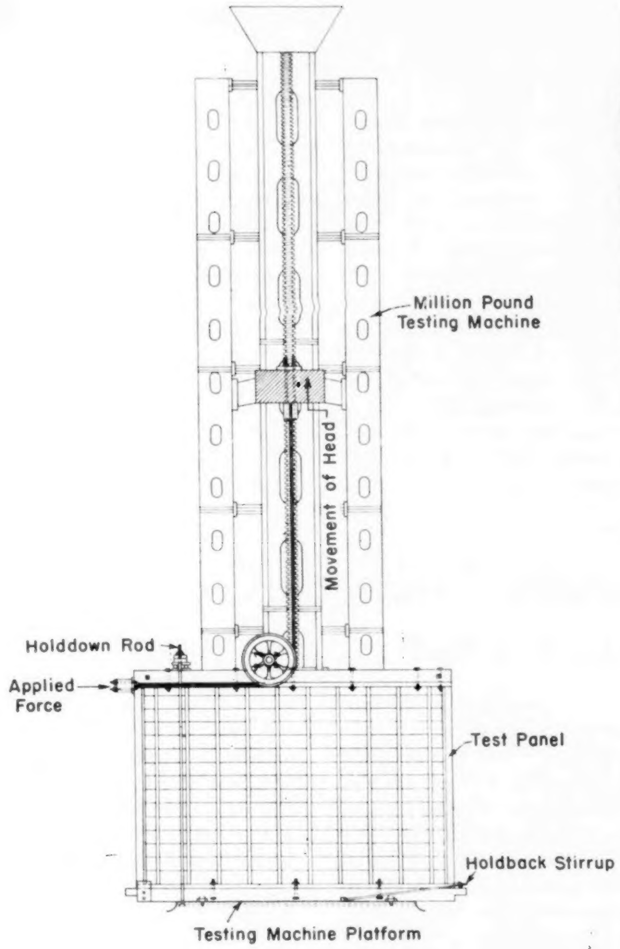

Fig. 15.—Racking Test of House Wall Panel.

Fig. 16.—Experimental Unit Built of Sandwich House Panels Constructed at Forest Products Laboratory.

control specimens in shear (Fig. 1). The apparatus used for applying the constant load is shown in Fig. 14. Shear was induced in the specimen by applying tensile forces as for the fatigue tests. Deformations were measured with mirrors mounted on knife-edges supported by projecting ears of the facing material, and readings were taken at various time intervals until failure occurred. The time to failure was obtained by arranging the apparatus to interrupt the circuit to an electric clock that was started when the load was first applied.

In order to determine how sandwich constructions will behave at elevated temperatures and under conditions such as are met in operating aircraft at supersonic velocities, tests of long and short columns, shear tests, tension tests, and tests of aluminum lap joints were conducted at elevated temperatures up to 600 F. The testing methods were similar to those outlined previously.

Tests of Other Sandwich Constructions

The Forest Products Laboratory's work on sandwich constructions of a type proposed for use in housing has dealt with constructions usually much thicker and of weaker materials than sandwiches for aircraft. They were composed of aluminum or plywood facings on cores of expanded paper honeycomb or corrugated paper. Tests were conducted on full-size panels, such as would be used in a house, and conditions of support and loading simulated actual use as much as possible.

Floor, wall, and roof panels were subjected to bending loads. Panels were supported at the ends, and the load was usually applied at two quarter points. Deflections up to design load and also to $2\frac{1}{4}$ times design load were obtained by observing the motion of a scale attached at the center of the span relative to a fine wire stretched from the end reaction points. Several panels incorporating large overhang for roofs were loaded under dead load of loose sand up to $2\frac{1}{4}$ times the design load. Maximum loads were always obtained by testing the panels under loads applied a two quarter points until failure occurred.

Floor, wall, and roof panels were also tested under impact bending loads. This was done by supporting the panels at the ends, as for the static type of bending test, and applying loads at the center of the panel by dropping a 10-in. diameter, 60-lb. sandbag from various levels. The sandbag was raised to a required height above the center of the panel and dropped by tripping a release mechanism. The bag was then dropped from higher levels in increments of 1 ft. until failure occurred. Central deflections at impact were measured by observing the motion of a scale placed under the panel and in contact with it at the point of impact. This scale was held in a sleeve by friction. Thus, when the impact deflected the panel, the scale was pushed through the sleeve the distance that the panel deflected.

Another test performed on all panels was the indentation test. The panel was supported on the full span and loaded at the center through a bar 1 in. in diameter. The deflection was observed with a scale and wire apparatus, and indentation with a dial gage.

Wall panels were tested in compression. The lateral deflection and the total compression were measured with dial gages.

Racking tests were made on wall panels to simulate conditions of wind load on the walls of a house. The apparatus used is shown in Fig. 15. For some panels which were to be used in one-story houses, the hold-down rod was not used because it was felt that the roof loads would usually be so light that the compression imposed by the hold-down rod would not be realistic. Deflections of the panel at various points were measured with dial gages.

Durability of housing sandwich constructions was determined by comparing the flexural strength of small specimens after exposure with that of control specimens. The exposure cycle used was as follows:

1. Immersed in water at 122 F. for 1 hr.
2. Sprayed with wet steam at 194 to 200 F. for 3 hr.

3. Stored at 10 F. for 20 hr.
4. Heated in dry air at 212 F. for 3 hr.
5. Sprayed with wet stream at 194 to 200 F. for 3 hr.
6. Heated in dry air at 212 F. for 18 hr.

Specimens were subjected to six complete cycles prior to testing. Samples were also tested wet after soaking in water for several days.

The behavior of panels under unsymmetrical conditions of temperature and humidity was observed by placing the panels in wall openings between two rooms, one maintained at room temperature and humidity conditions and the other at −20 F. The amount of bowing or warping was measured with dial gages. The amount of water absorbed was determined by weighing the panels periodically. The occurrence of icing inside the panel was checked by cutting open the panel.

In order to obtain a realistic test of panels under actual use conditions, a unit consisting of sandwich constructions in the walls, floor, and roof was built on the laboratory grounds (Fig. 16). This unit has several different types of panels, placed individually so that they can be easily removed or replaced. Since they are not connected structurally to each other, individual performance with regard to bowing and warping can be measured periodically. The indoor conditions can be controlled at any temperature and humidity that may be expected in a dwelling. This unit has been under test for about $2\frac{1}{4}$ yr.

Conclusion

Research on sandwich constructions of both the aircraft and the housing type is continuing at the Forest Products Laboratory, and many of the data that have been obtained are available in report form. Those reports with special regard to testing methods are *Report No. 1555*, "Methods of Test for Determining Strength Properties of Core Material for Sandwich Construction at Normal Temperatures" and *Report No. 1556*, "Methods for Conducting Mechanical Tests of Sandwich Construction at Normal Temperatures."

Durability Tests of Metalite Sandwich Construction[1]

By David G. Reid[2]

The Chance Vought Aircraft Division of United Aircraft Corp., in cooperation with the U. S. Department of Navy, Bureau of Aeronautics, has developed a lightweight, high-strength sandwich construction known by the trade name of Metalite. This composite material consists basically of a relatively thick end-grain balsa core to which are bonded thin facings of high-strength aluminum alloy. It has provided the designer with a material having properties of excellent aerodynamic smoothness, a high strength-weight ratio, and freedom from skin buckling not generally attained by conventional sheet metal construction.

It was developed primarily for design and construction of carrier-based naval aircraft that would operate in all types of climatic conditions throughout the world. It was therefore paramount that the material possess a high, uniform quality in order that deteriorating media such as moisture, fungus, salt water, and temperature extremes would not reduce structural integrity throughout the operational life of the aircraft. In view of these rigid requirements, initial development was directed toward producing the highest quality practicable and conducting varied and exhaustive tests to establish the suitability of this type construction for use in high performance naval aircraft.

It is the purpose of this paper to discuss certain of the typical test procedures used by Chance Vought Aircraft to determine the effects of accelerated and natural exposure on its strength and general efficiency. An account of the broader aspects of its development has been presented in another paper.[3]

Accelerated Exposure

The use of balsa as an end-grain core for sandwich construction originally posed many questions regarding durability because of its known inherent susceptibility to moisture absorption and the resultant dimensional change. In spite of available data on balsa at that time, it was believed that the particular use of balsa as an end-grain core would show a different behavior in the completed sandwich construction. This assumption was prompted by the fact that the end-grain surface is sealed by the metal facings and the exposed flat-grain balsa at the panel edges is a relatively small surface area compared to that of the bonded area of the sandwich panel. A more complete evaluation of balsa as a core material has previously been presented by the author.[4]

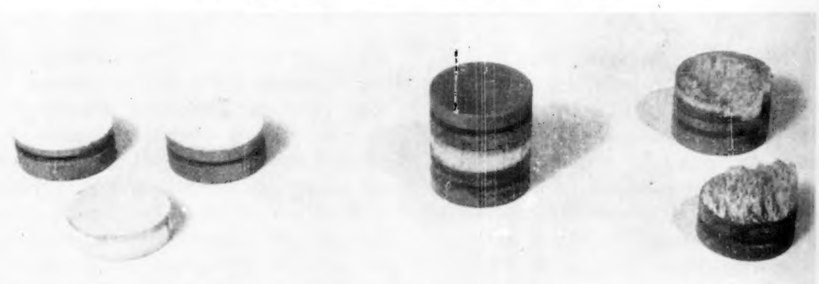

Fig. 1.—Standard Tension Sample.

A test typical of those devised to study the general durability of Metalite was the exposure of sandwich panels having end-grain cores of balsa or mahogany to cycles of water immersion, subzero temperature, and elevated temperature. Mahogany was selected as a comparison standard since it is used as a core insert and edging material in Metallite and possesses known characteristics of good durability, bondability, and dimensional stability.

Panels of end-grain balsa and end-grain mahogany were fabricated using the Cycleweld C-3 cement and Durez 12041 adhesive system. The facings were 0.012 by 14 by 14-in. 24S-T-clad aluminum alloy. The cores were $\frac{3}{8}$ in. thick and were conditioned in a con-

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NOTE.—DISCUSSION OF THIS PAPER IS INVITED, either for publication or for the attention of the author. Address all communications to A.S.T.M. Headquarters, 1916 Race St., Philadelphia 3, Pa.

[1] This paper was presented at a meeting of Committee C-19 on Structural Sandwich Constructions, held in San Francisco, Calif., October 13, 1949, during the First Pacific Area National Meeting of the Society.

[2] Supervisor, Engineering Structures Materials, Chance Vought Aircraft Division of United Aircraft Corp., Dallas, Tex.

[3] H. B. Gibbons, "Experiences of an Aircraft Manufacturer with Sandwich Material," *Quarterly Transactions*, Soc. Automotive Engrs., Vol. 1, No. 3, July, 1947, pp. 415–428.

[4] D. G. Reid, "Balsa Wood as an End-Grain Core Material in Sandwich Construction," presented at National Research Council—Office of Naval Research Symposium on Wood held in Washington, D. C., June 16, 1949.

[5] Federal Specification QQ-M-151.

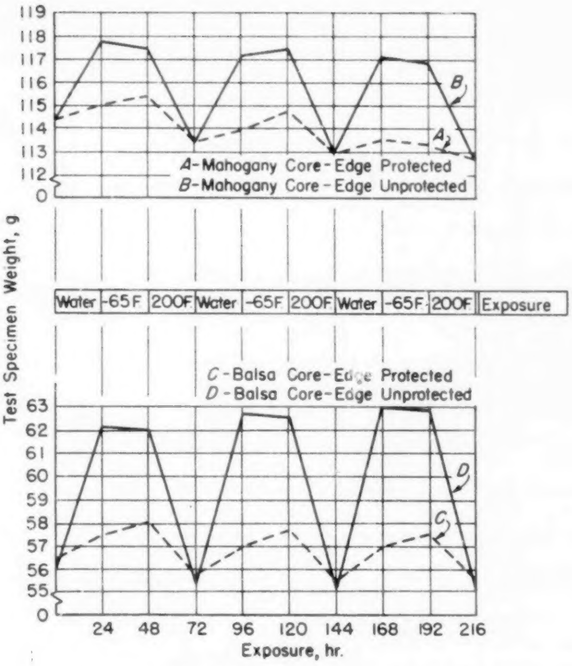

Fig. 2.—Weight Change During Cyclic Exposure.

TABLE I.—EFFECT OF ACCELERATED CYCLIC EXPOSURE ON TENSILE STRENGTH.

Specimen Treatment	Tensile Strength of Sandwich, psi.	
	Balsa Core	Mahogany Core
Exposed 3 cycles, unprotected	1900	1610
	1675	1665
	1810	1810
	1660	1650
	1550	1730
	1500	1500
	1740	1500
	1900	1500
	1550	1470
	1660	1830
Exposed 3 cycles, protected	1765	1610
	1700	1835
	1555	1730
	1760	1900
	1765	1580
	1650	1870
	1600	1700
	1820	1740
	1750	1710
	1690	1760
Controls	1570	1640
	1590	1570
	1720	1610
	1510	1570
	1660	1580
	1510	1500
	1600	1530
	1670	1540
	1690	1520
	1630	1500

NOTE.—One complete exposure cycle consists of 24 hr. immersion in tap water at room temperature, 24 hr. at −65 F. and 24 hr. at 200 F.

trolled atmosphere of 75 to 80 F. and 50 to 55 per cent relative humidity prior to panel-assembly and bonding. After bonding, the sandwich panels were conditioned in the same controlled atmosphere. From each panel six test specimens, 4 by 6 in. in size, were prepared. Two test specimens from each panel were retained as controls, two were left with the specimen edges unprotected, and the edges of the remaining two were protected with two coats of Specification AN-V-26 spar varnish sealer plus one top coat of aluminized spar varnish sealer. The 4 by 6-in. test specimens were then conditioned to equilibrium weight in the controlled atmosphere previously described and their weight determined to the nearest 0.01 g.

The edge-protected and unprotected test specimens having either mahogany or balsa cores were exposed to three cycles, each cycle consisting of immersion in tap water for 24 hr. at room temperature, followed by 24 hr. at −65 F. in a refrigerated chamber and ending with 24 hr. at 200 F. in an electrically-heated oven. The weight of individual test specimens was determined at the beginning and end of each single phase of each cycle. These data are summarized in Fig. 2. It may be noted that the test specimens having edges protected with the standard sealer finish exhibited only a small change in weight throughout exposure, and the balsa core specimens absorbed slightly greater amounts of moisture than the mahogany core specimens. As a check to determine the quantitative effect of exposure on strength, circular tension specimens, as shown in Fig. 1, were cut from the exposed test specimens and from those retained as controls. The 2-sq. in. circular test specimens were bonded between duraluminum tension blocks with Redux adhesive and then tested in tension (perpendicular to plane of sandwich) until failure. Testing was done using self-aligning grips in a Baldwin-Southwark Universal Testing Machine of 120,000 lb. capacity. The data in Table I show the tensile strengths of samples taken from the exposed protected and unprotected specimens and the specimens retained as controls. It may be noted that no significant reduction in tensile strength resulted for protected or unprotected specimens having either balsa or mahogany cores. Considering the severity of the exposure test, the data proved of great value in that such exposure would be less detrimental on large panels normally used in airframe construction because of the lower ratio of panel edge area to the bonded area of the entire panel. In all cases the general level of tensile strength for the exposed samples was in excess of the minimum required for acceptance in production. The acceptable minimum established for production quality control is a 900 psi. average for four specimens with no single value to be less than 700 psi.

One of the major problems confronting the aircraft designer of today is the effect of service temperatures on the strength of aircraft structures. Since Metalite sandwich construction was developed for use in highly stressed airframe components, it became necessary to study its behavior throughout wide ranges of temperature. Of particular importance was the effect of various temperatures on the strength of the balsa core as well as the bonding agents used to secure the facings to the core. To establish the general tensile strength characteristics at temperatures ranging from −80 F. to 250 F., a comprehensive test program was carried out such that all factors of materials and fabrication were carefully controlled. In addition, the experiment was replicated three times to provide necessary data for determining the range of values for any given condition of test.

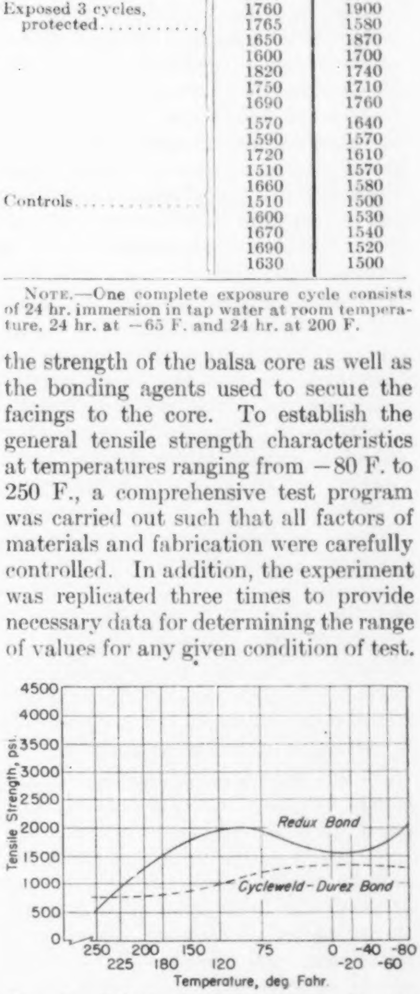

Fig. 3.—Effect of Temperature During Test on Tensile Strength.

Metalite sandwich panels, 4 by 6 in. in size, were fabricated with the Cycleweld-Durez adhesive system. The facings were 0.012-in. 24S-T clad aluminum alloy and the core was 8.0 lb. per cu. ft. balsa, $\frac{3}{8}$ in. in thickness. Three sets of 36 panels each were prepared such that each set was fabricated in separate bonding cycles using cores made from one selected stick of balsa. From each panel, six circular tension specimens were cut and bonded between duraluminum tension grips with Redux adhesive as shown in Fig. 1. The 216 tension specimens of each set were assigned identify-

ing numbers and then randomly divided into twelve subgroups of 18 specimens each. Each of the twelve subgroups was then tested at one assigned temperature condition between −80 F. and 250 F. At temperature levels below room temperature, the specimens were conditioned and tested in an altitude chamber maintained at the desired temperature for the test. The load was applied to each specimen by means of hydraulic cylinders and self-aligning testing grips. The ultimate load was recorded by electric strain gages attached to the linkage system of the hydraulic loading mechanism. At temperatures above room temperature, the specimens were conditioned to the desired test temperature in an insulated chamber heated by electric elements and mounted between the heads of a Baldwin-Southwark Universal Testing Machine. When the conditioning temperature had been reached and maintained, the specimen was tested in tension until failure.

Another complete series of test panels and specimens were prepared in an identical manner except that Redux adhesive was used as the facing to core bonding agent. This was done in order to observe the behavior of two distinct adhesive systems under similar conditions of test at various temperatures.

In Fig. 3 are summary curves showing the average tensile strength of Metalite sandwich construction at various temperatures from −80 F. to 250 F. These data proved to be a valuable asset in predicting the general behavior of Metalite at various temperatures and provided a sound basis for planning and conducting additional test programs on the strength of structural elements.

In the development and use of materials for naval aircraft construction, one of the most important considerations is the effect of corrosive salt spray atmosphere on strength. This factor was of particular importance in evaluating the efficiency of Metalite. Numerous tests have been conducted to study effects of corrosion at the bond interface. The data obtained have not served directly to predict behavior in service, but it has been useful in making rapid comparisons of the effects of variations in bonding materials and fabrication processes.

One typical test consisted of exposing unprotected cantilever beam specimens to salt spray and then testing them in fatigue. The specimens were fabricated with the Cycleweld-Durez system using 0.020 in. 75S-T clad aluminum alloy facings and $\frac{7}{16}$ in. thick, 9.0 lb. per cu. ft. balsa cores. After fabrication, the unprotected specimens were exposed for various periods of time in a standard salt spray atmosphere.[5] Testing in fatigue was done using a Krouse testing machine. The repeated load was applied (1800 cycles per min.) such that a complete reversal stress of ±20,000 psi. (static) was obtained in the metal facings until specimen failure. The total number of cycles at time of failure was recorded for each specimen and plotted against number of hours exposed to salt spray as shown in Fig. 4. The failures of all specimens exposed to salt spray and those used as unexposed controls were in the metal facings. The general decrease in number of cycles to failure with an increase in number of hours exposure was due to localized stress concentrations caused by pitting and corrosion of the metal facings.

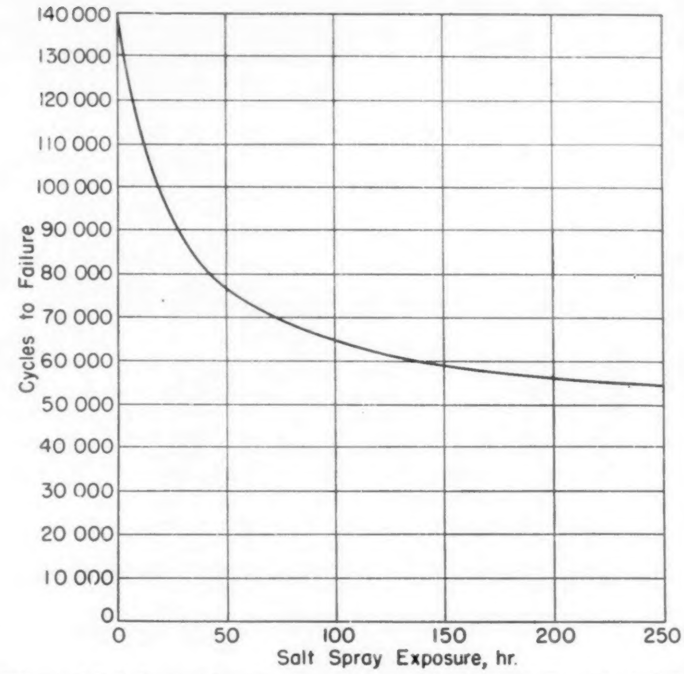

Fig. 4.—Effect of Salt Spray Exposure on Fatigue Strength of Unprotected Specimens.

Another typical test for determining the effect of salt spray exposure was determining its effect on the tensile strength of Metalite construction. One 16 by 32-in. production panel fabricated with the Cycleweld-Durez system was selected for test. The panel was made of 0.016-in. 24S-T clad aluminum alloy faces and 9 to 12 lb. per cu. ft., $\frac{3}{16}$-in. thick balsa core. From this panel 120 standard tension samples were cut and bonded between duraluminum tension grips with Redux adhesive. The 120 specimens were randomly divided into six groups of 20 specimens each. Retaining one group as a control, the remaining groups were each exposed for various periods of time to a standard salt spray atmosphere. The specimen edges were unprotected during exposure and therefore represented a very severe test as regards the relation of exposed edge area to the total bonded area. After exposure, the specimens were

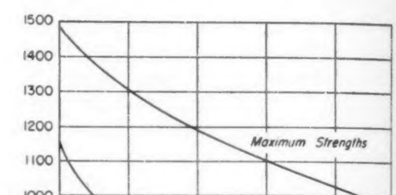

Fig. 5.—Effect of Salt Spray Exposure on Tensile Strength of Unprotected Specimens.

tested in tension to failure in a Baldwin-Southwark Universal Testing Machine using self-aligning grips. Figure 5 shows curves presenting the effect of salt spray exposure on the tensile strength. In order to indicate the range of strength values obtained, curves were drawn through the maximum and minimum values of each group in addition to the curve indicating the mean strength of each group *versus* exposure time. It is of interest to note that the actual range of strength values remains fairly constant regardless of length of exposure time. Subsequent tests in which specimens were edge-protected and tested in

Fig. 6.—Model F4U-4 Metalite Stabilizer.

tension after salt spray exposure for periods up to 1800 hr., showed no significant loss in strength. These data served to demonstrate the protective properties of the finish system, particularly in cases where the ratio of specimen edge area was high with respect to total bonded area.

Service Exposure

The most significant data on the durability of Metalite construction have been obtained by testing Model F4U-4 stabilizers after various periods of service operation. Under contract with the U. S. Navy Department, Bureau of Aeronautics, approximately 400 stabilizers (Fig. 6) were produced by Chance Vought Aircraft for installation on Model F4U-4 airplanes that were operating in the Caribbean and Pacific areas. Periodically stabilizers were returned to Chance Vought for static test to destruction to determine if any loss in structural efficiency had resulted. In addition, individual specimen tests of the basic sandwich were made after static test. Table II presents results of the static tests of stabilizers after varying lengths of service operation. According to the data obtained, no loss in structural efficiency has resulted regardless of length of service, since the primary static test failures did not occur in the sandwich construction. Tension tests of the sandwich have shown no loss in bond strength or deterioration of the balsa core.

TABLE II.—STATIC STRENGTH OF MODEL F4U-4 STABILIZERS AFTER SERVICE OPERATION.

The Static Test Loading Condition Simulated a Modified Inverted Low Angle of Attack Condition.

Stabilizer Serial	Flight Time, hr.	Service Time, months	Area of Service Operations	Failure at per cent Design Ultimate Load[a]	Type of Failure
No. 58	....	2	Caribbean	165.0	Attachment fittings
No. 59	....	2	Caribbean	165.0	
No. 45	238.9	4	Caribbean	166.5	
No. 19	525.2	12	Caribbean	165.0	
No. 300	604.9	..	Pacific	153.9	Metal beam flange
No. 27	908.9	..	Caribbean	154.1	
No. 57	1240.5	..	Caribbean	150.0	

[a] These values are in terms of per cent of design ultimate load for conventional all-metal stabilizers for previous Model F4U series. The minimum value for the Metalite design is 150 per cent.

Conclusion

One of the most important considerations in determining durability has been that of correct interpretation of the data obtained. The application of information derived from accelerated tests is limited as far as predicting actual service durability but is invaluable in making comparisons of various materials and fabrication processes. In the final analysis, experience has shown that actual service exposure testing is the only means for determing true durability of this type material. However, the successful development of Metalite would not have been possible unless specific tests involving accelerated cor. ditions had not been conducted.

There are several important factors involved in test programs to determine durability which have proved to have a direct bearing on applicability of results obtained. These are panel size, panel construction, number of tests, control of specimen preparation, test conditions, and control of test procedures. When possible, test programs are designed such that the data obtained can be statistically analyzed in order to make an accurate estimate of the mean, minimum, and maximum strengths as well as variance. These data can then be used with more reliability as bases for establishing quality control standards and structural design allowables.

Report of the Engineer's Council for Professional Development

The Seventeenth Annual Report of the Engineers' Council for Professional Development gives an encouraging across-the-board picture of what the Engineering Profession is doing to improve the competence of its members and to make engineering work more rewarding in personal satisfactions. For this reason the 47-page recently published document deserves a careful reading by all engineers who are interested in the betterment of the profession.

The ECPD is a conference organized in 1932 to enhance the professional status of the engineer through cooperative efforts of the following eight engineering organizations: Am. Soc. Civil Engrs., Am. Inst. Mining and Metallurg. Engrs., Am. Soc. Mechanical Engrs., Am. Inst. Electrical Engrs., Nat. Counc. State Boards of Engineering Examiners, The Am. Soc. Engineering Education, The Engineering Inst. of Canada, and the Am. Inst. Chem. Engrs. It concerns itself with the professional, technical, educational, and legislative phases of the life of the individual engineer. Its principal work is done by four standing committees who address themselves to the betterment in methods of selection and guidance of the student engineer, the content of his college curriculum, the orientation of the graduate engineer in industry, and finally the procedures by which he is awarded professional recognition. The actual work of the ECPD is done by some 300 educators and practicing engineers who volunteer their services in the interest of the profession.

In the lead article, J. W. Parker, retirg ECPD chairman, calls attention to the progress achieved during the past year:

1. The Pre-Engineering Inventory, a battery of tests for aptitude and achievement developed under ECPD sponsorship, was placed on a self-supporting basis and made more accessible to guidance counselors and persons desiring to be tested.
2. In the field of professional training, steps were taken to establish a 7-point program directed toward extension of educational processes into the period following graduation. The plan envisages an organized program for continuing engineering education into and through the years of active employment.
3. With regard to professional recognition the Council adopted uniform nomenclature for designating the several grades of membership in constituent societies and established minimum standards for admission to the respective grades.

Copies of the report can be obtained from ECPD, 29 West 39th St., New York, N. Y. Price per copy is 50 cents.

Correlation of Accelerated Weathering Machines

By Roy W. Hill,[1] George S. Cook,[1] and William E. Moyer[2]

SYNOPSIS

This report covers an investigation conducted at the U. S. Army Engineer Research and Development Laboratories to correlate the exposure results obtained from the Atlas Twin Arc Weatherometer with those obtained from the National Carbon X1A Accelerated Weathering Machine. In the course of this investigation, several possible bases of correlation were examined. The one chosen, the amount and type of change of color of paint on test panels, the preparation of which was carefully controlled, was proved by experiment to provide a reproducible test of the effects of exposure of the panel to the operation of the machine.

The report concludes that the results obtained from accelerated weathering in the National Carbon X1A and the Atlas Twin Arc Weatherometers are correlated if the paint is dip-applied on primed metal panels; the machines are both operated in accordance with Federal Specification TT-P-141a, modified to control machine temperatures at 155 ± 5 F.; and if the Atlas Weatherometer is equipped with the 68-12 control cam.

DEVELOPMENT OF TEST METHOD

Objectives:

THE Chief of Engineers directed that the comparative effects of two types of weathering machines of different manufacture be determined. This would require the use of a testing procedure not then in existence. It was necessary to determine the variations in results caused by the lack of uniformity in the test panels themselves before the variations caused by the machines could be determined.

A preliminary investigation was launched, therefore, to develop a method of testing, an accelerated weathering machine and its effects on paint panels exposed to its operations. That investigation is reported below. The criteria developed in this investigation were then applied to the primary problem posed by the Office, Chief of Engineers—that of correlating the operational effects of the two types of machines.

Previous Work:

The laboratory tests of paints with which this investigation is concerned proposed to measure the durability that can be expected of paint coatings in actual outdoor use. The variables affecting this durability include the many physical properties of the paint coating itself and the innumerable and constantly varying conditions of outdoor exposure to which the coatings are subjected.

Actual field test conditions are, of course, beyond the control of the agency making the test, and because of their unpredictability are impossible to duplicate in the laboratory. Too, these tests take years to complete, and procurement of paint by specification cannot wait upon their completion.

The alternative available has been to test paints in the laboratory, under accelerated, simulated exposure conditions. Various laboratory machines and techniques have been devised which, when used in combination with, tend to duplicate to a limited extent the actual field exposure conditions. These include abrasion testers, salt spray exposure cabinets, humidity cabinets, water immersion tanks, and accelerated weathering machines.

However, even with these machines, difficulties have been encountered because no standard procedure has ever been established for laboratory exposure that would duplicate, for example, the sequence of conditions found in outdoor exposure. In addition, no completely satisfactory set of standards of outdoor exposure has ever been established.

In the case of accelerated weathering machines, the additional difficulty has existed that results obtained from machines of the same manufacture, as well as from machines of different design and manufacture, have been impossible to correlate either among themselves or with outdoor exposure. This, has, of course, cast serious doubt on their usefulness.

Considerable work has been done by various agencies in an effort to establish some general basis of correlation between accelerated weathering and outdoor exposure and to determine the limitations of the machines. The results of this work have served to point out the existence of the limitations, without, however, defining them. Beck (1)[3] found the machines of value in

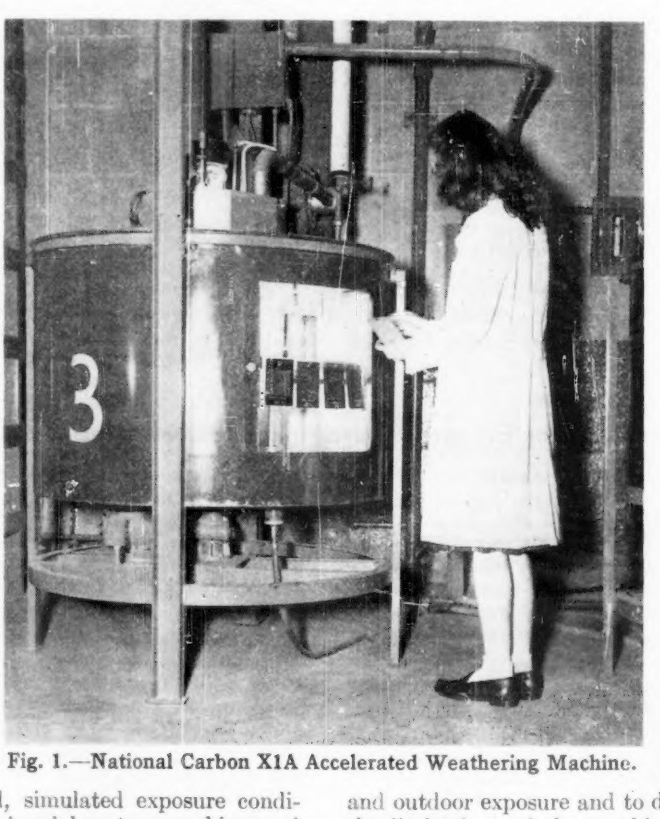

Fig. 1.—National Carbon X1A Accelerated Weathering Machine.

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[2] National Lead Co. Research Lab., Brooklyn, N. Y.

[3] The boldface numbers in parentheses refer to references at end of this paper.

tests of top coats only. He discovered that changes in color, such as fading, darkening, and chalking, could be correlated reasonably well with outdoor exposure, but no predictable relationships could be shown between machines and outdoor exposure in testing such important paint failures as checking, rusting through, or blistering. Committee D-1 on Paint, Varnish, Lacquer and Related Products of the American Society for Testing Materials under the chairmanship of H. A. Nelson (**2**) on the other hand, declared after an extensive testing program that, in general, the accelerated tests predicted reasonably well the general results of outdoor exposure. Iliff (**3**) found that National Carbon X1A machines gave a significant degree of correlation with the results obtained by actual exposure to Florida weather, but that the Atlas Twin Arc Weatherometers gave results just under the significant level of correlation. Williams (**4**), in a study that seemed to limit the usefulness of the other investigations, found that water supply, duration of water exposure, maximum temperature, and the duration of the maximum temperature tended to influence the results obtained in either machine.

The more general use of the National Carbon machine in the preparation of Federal wartime paint specifications was based, in general, on Iliff's work, and the fact that at least with Florida weather a truly significant correlation had been shown. With the cessation of hostilities, there came into existence a growing opinion that these specifications could, and probably should, be written on the basis of using either the National or the Atlas machine, if results from the two could be properly correlated, or if it could be shown by sufficiently comprehensive tests that there is no essential difference in the results obtained with these machines.

In the assignment of the problem for solution, it developed that the Engineer Research and Development Laboratories was one of the few installations that had models of both machines. ERDL equipment included three National machines and two Atlas, so that any test conducted at the laboratories could not only compare the machines with each other, but could compare duplicates of each machine. Therefore, the Laboratories were directed in 1946 by the Chief of Engineers, to investigate the possibility of correlating the two types of machines.

Equipment:

The National Carbon X1A Accelerated Weathering Machine (Fig. 1) is of the open carbon arc type. Corex D filters are used over the arc in operation so that the light transmitted is similar to sunlight. In this machine, test panels are subjected to continuous exposure to this light and receive 18 min. of water spray once in each 2-hr. rotation. Carbons are replaced after each 10 hr. of operation of the machine. There are two circular racks, one above the other, which rotate once in each 2 hr. of machine operation. Three of these machines were tested.

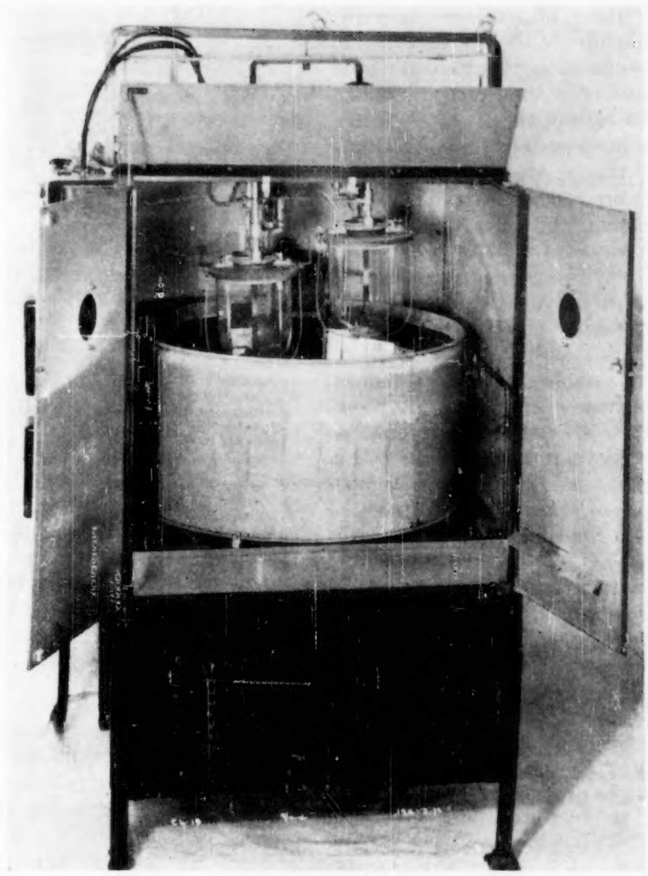

Fig. 2.—Atlas Twin Arc Weatherometer.

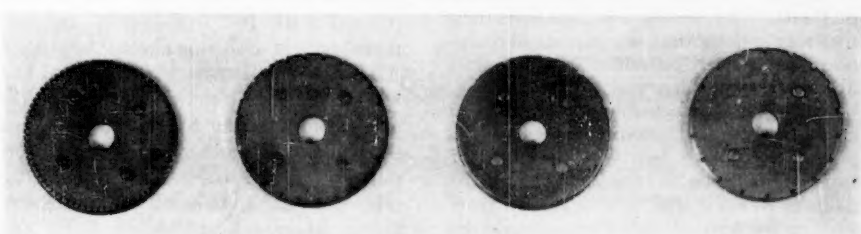

Fig. 3.—Atlas Control Cams.

The Atlas Twin Arc Weatherometer (Fig. 2) is of the closed carbon arc type and subjects the test panels intermittently to water spray and continuously to a light similar to sunlight. The circular rack rotates once in each minute of machine operation. Arc operation is continuous, and the water-light relationship is adjustable by a changeable cycling cam (Fig. 3). Two of these machines were used in the correlation.

Investigation:

In developing a method for solving the problem posed by OCE, the previous work, outlined above, was thoroughly evaluated by ERDL. It was obvious at once that in order to test the machines, rather than the samples exposed in them, it would be necessary first to decide on the most useful basis for a correlation, and then to eliminate, in so far as possible, the other variables in the tests.

The primary paint interest of the Corps of Engineers centers on camouflage coatings. These are usually of a temporary nature, with color and color permanence of primary importance, and the mechanical protection offered by the coating, secondary. Previous work had shown that it is in the field of color change that accelerated weathering machines tend to give results most easily

related to those of outdoor exposure. It was therefore decided to establish a method for correlating the two machines on the basis of change of color under exposure in each of them.

For the purposes of this correlation, effects of the accelerated weathering machines were restricted to the evaluation of changes of color on the test panels, in terms of relative brightness, dominant wave length, and percentage of purity. Relative brightness is that attribute which distinguishes between light and dark samples of the same color, the lighter sample having the higher relative brightness. The dominant wave length is the attribute that distinguishes one color from another in terms of its common name, that is, red from yellow. Percentage of purity indicates the freedom of a color from admixture with other colors.

Factors involved in the testing of color changes due to weathering were determined to be of the following nature:

1. *Color.*—Any satisfactory test method developed must be equally applicable to all colors.

2. *The Type of Paint.*—The paint tested must, to provide useful answers, be of a type in use by the Corps of Engineers, and must be available in a wide variety of colors.

3. *Method of Application.*—Paint may be applied by the dip, brush, or spray methods. The problem of the investigators was to determine which method of application would introduce the smallest number of variables, and would therefore be most easily susceptible of reproduction and experimental control. While the paint selected for test was designed for brush application on wood surfaces in the field, it was felt that any deviation from such a method of application would be valid, provided it afforded a better laboratory control, and provided it did not materially alter the effects obtained by brush application.

4. *Type of Test Panel.*—This involved essentially the same problem posed by the method of application. The investigators were concerned primarily with control of the reproducibility of the test panels. Variation in grain, cut, and color of wood made the selection of sufficient duplicate panels difficult. Variations in application and penetration of primer made reproducibility even more difficult. Steel panels, dip coated with an efficient metal primer, remained as the only inexpensive alternative for furnishing a reproducible and satisfactory surface for painting. Since the investigation was to be restricted to the correlation of the weathering machines for color change only, the lack of film failures specific to painted wood was considered unimportant. However, to make sure that all possible relevant factors were considered, it was decided to include panels of both steel and wood.

5. *Rest Periods During the Test.*—This factor was introduced for consideration as a variable because the results of some of the previous investigations indicated that it might tend to influence results obtained. No special tests were made for this factor although general observations were recorded.

TABLE I.—OPERATING CONDITIONS OF NATIONAL X1A MACHINES.

Type of current—230 v., 60 cycle, single-phase, a.c.

	Standard	Machine 1	Machine 2	Machine 3
Average voltage at arc	50	50	50	50
Average amperes	60	60	60	60
Distance from arc to panels, cm.	45	45	45	45
Type of glass enclosing arc	Corex D	Corex D	Corex D	Corex D
Average total burning time of carbons, hr.	10	10	10	10
Water spray pressure, psi.	25 to 40	30	30	30
Interval between successive wettings, min.	102	10[illegible]	92	105
Duration of each wetting, min. and sec.	18	12:20	18:25	11:05

TABLE II.—OPERATING CONDITIONS OF ATLAS TWIN ARC WEATHEROMETERS.

Type of current—208 to 245 v., 60 cycles, a.c.

	Standard	Machine 1	Machine 2
Average amperes	30 to 34	32	32
Average voltage at arc	125 to 145	130	130
Type of glass enclosing arc	Pyrex	Pyrex	Pyrex
Average burning time of carbons, hr.	24	24	24
Water spray pressure, psi.	25 to 40	30	30
Interval between successive wettings, min.	16 to 17	16 to 17	16 to 17
Duration of each wetting, min.	3 to 4	3 to 4	3 to 4

Procedure:

The paint selected for testing was a standard coating, conforming to Corps of Engineers Specification for T-1215, "Paint, Camouflage, Oil Type," in all 17 of its colors. This is a standard linseed oil paint. Test panels were chosen from selected red cedar and cold-rolled steel. The red cedar panels were primed with red iron oxide, and the metal panels with zinc chromate primer. After priming, the panels were aged two weeks at room temperature before the application of the top coating. Then separate sets of both types of panels were painted by dip, brush, and spray methods, and an additional two weeks of aging at constant temperature and humidity was allowed. Each panel was measured in a spectrophotometer, the results being recorded on standard curve sheets. These curves supplied the data for the computation of dominant wave length, percentage of relative brightness, and percentage of purity for each panel.

The five machines to be used in the investigation were examined for conformance to Federal Specification TT-P-141a. This comparison is given for the National Machines in Table I and that for the Atlas in Table II. The filtered water used in the machines contained 74 ppm. of dissolved solids: 32.5 ppm. calcium, 2.3 ppm. magnesium, 27.3 ppm. sulfate (SO_4), and a trace of iron.

Eight colors were exposed in the machines, using both wood and metal panels, prepared by all three methods. Complete sets were not used in all cases, because of the space limitations of the machines. After total exposures of each panel for 300 hr. spectrophotometric curves were again taken.

During the whole test run, periodic temperature readings of each machine were recorded from black panel thermometers, considerable variations being noted. The machines were then adjusted to operate at 155 ± 5 F. which represented the low operating limits of the National Carbon machines.

After the adjustment, a second set of panels, in four camouflage colors, was placed in each machine and exposed 300 hr. Pre- and post - exposure spectrophotometric curves were obtained for these panels.

Results:

All the spectrophotometric curves for original and exposed panels were then converted into their respective dominant wave length, percentage of relative brightness, and percentage of purity. The changes in these three numerical values for color, that were induced by weathering, are the basic data on which results of these tests were evaluated and compared. A complete listing of the before and after weathering values for the three color factors is given in Table III.

Analysis:

The amount of percentage change in dominant wave length, relative brightness, and purity was set down in Table IV. It was now necessary to study and interpret these data to determine how much each variable in the testing procedure had affected the results in order to determine the effects of the machines themselves.

Effect of Color.—The effect of the use of different colors was investigated first to determ[illegible]er the color that showed the least change in one machine would show the least in all machines, irrespective of the surface on which it was applied or the method of application. The data of Table IV were subjected to

TABLE III.—DEVELOPMENT OF TEST METHOD—RESULTS OF 300 HR. OF ACCELERATED WEATHERING ON PAINT FINISHES.

Panels	Machines	No.	Original Finish[a] λD[b] D	λD[b] B	λD[b] S	Relative Brightness, per cent D	B	S	Purity, per cent D	B	S	Finish After 300 Hours[a] λD[b] D	λD[b] B	λD[b] S	Relative Brightness, per cent D	B	S	Purity, per cent D	B	S
Green																				
Metal Panels	National Carbon Machines	1	508	506.2	506.8	13.6	13.3	13.2	14.7	14.0	14.0	510.8	511.4	521.8	16.5	15.4	16.6	10.7	11.2	11.4
		2	506	508	506.1	13.5	13.5	13.2	14.2	13.5	13.8	513.8	517.2	521.4	16.9	16.4	16.2	10.7	10.7	11.4
		3	507	506	506.8	13.4	13.2	13.3	14.5	14.2	14.0	516.2	518.2	521.8	17.4	16.8	21.3	10.5	10.9	11.4
	Atlas Machines	1	510.2	506.2	505.6	13.7	13.3	13.3	13.5	14.0	14.0	511	513.5	515.5	14.1	14.1	14.3	11.0	10.8	10.8
		2	507	507.8	507.8	13.5	13.6	13.4	13.3	13.7	13.5	515.3	510.8	512.0	13.3	14.2	13.4	11.7	11.3	11.7
Wood Panels	National Carbon Machines	1	507	506	506.8	13.6	13.4	13.1	14.3	14.0	14.2	514.5	511.5	512.4	17.8	17.5	17.4	10.3	11.0	10.9
		2	507.5	505	506	13.6	13.2	13.1	12.4	14.8	14.2	517.6	511.3	509.6	18.1	17.2	16.4	10.3	10.8	11.4
		3	507.2	505	505.7	13.6	13.3	12.4	14.5	14.5	14.1	516.6	515.0	514.5	18.1	18.4	18.0	9.1	10.5	10.7
	Atlas Machines	1	507	506.5	505.8	13.6	13.2	13.2	14.4	14.0	13.8	531	541.0	529.0	20.5	20.9	19.8	12.7	16.6	12.8
		2	507	505.8	505.8	13.6	13.1	13.2	14.4	14.2	14.1	529.4	531.5	529.9	19.1	20.1	19.5	12.5	12.8	11.9
Dark Green																				
Metal Panels	National Carbon Machines	1	547.3	543.8	544.6	7.4	7.4	7.3	14.7	10.0	11.0	547.4	549.5	546.8	11.3	9.5	8.3	12.9	11.6	12.1
		2	550.3	543.8	543.4	7.0	7.4	7.3	9.5	10.2	10.4	547.5	550.0	546.0	10.8	9.8	9.2	12.3	12.9	11.6
		3	544.3	543.8	544.0	7.5	7.5	7.3	11.8	10.2	10.7	549.4	555.0	548.1	11.1	10.0	9.4	13.2	16.2	12.2
	Atlas Machines	1	545.0	544.0	548.0	7.4	7.4	7.2	12.0	11.0	12.5	548.0	549.0	554.0	9.8	9.1	9.0	13.0	11.5	15.5
		2	545.0	543.8	549.4	7.4	7.2	7.3	12.6	10.8	13.3	551.5	545.7	545.8	9.5	8.4	9.3	14.6	10.4	10.6
Wood Panels	National Carbon Machines	1	546.0	542.9	545.2	7.4	7.4	7.3	12.9	9.9	11.0	551.5	552.6	553.9	12.3	11.8	11.0	14.1	13.9	16.0
		2	544.0	544.5	543.0	7.4	7.4	7.2	12.0	10.5	10.6	548.0	551.7	552.0	12.4	10.5	10.5	11.8	13.0	14.3
		3	544.2	541.3	547.6	7.3	7.4	7.3	12.0	10.2	11.7	552.7	553.7	556.1	12.4	12.0	11.2	14.8	15.0	17.4
	Atlas Machines	1	543.0	550.0	544.0	7.3	7.4	7.3	12.0	12.5	10.2	559.0	560.8	563.0	13.8	13.4	12.6	20.0	19.0	13.5
		2	542.6	542.7	542.6	7.5	7.4	7.3	11.9	10.2	10.2	559.2	561.4	559.5	13.2	12.4	11.8	19.2	19.7	20.7
Light Green																				
Metal Panels	National Carbon Machines	1	568.4	566.8	559.8	14.3	15.7	15.9	30.0	34.5	32.5	576.6	568.3	567.7	17.9	16.8	17.3	31.3	32.1	30.4
		2	559.0	562.5	566.7	15.8	15.8	15.8	32.0	33.2	34.8	568.8	568.5	568.8	16.8	17.3	16.9	32.6	32.2	32.7
		3	560.2	564.5	560.3	16.0	16.4	15.7	32.3	36.0	32.0	568.4	569.0	568.5	17.1	17.0	17.4	32.2	31.8	31.8
	Atlas Machines	1	560.0	567.5	560.4	15.9	15.7	16.0	32.0	35.5	33.0	569.3	568.6	568.5	17.0	17.8	15.1	34.9	31.8	36.4
		2	567.0	564.6	561.7	16.3	15.7	15.9	34.0	35.3	33.0	569.0	568.3	568.5	15.2	14.8	14.6	35.0	34.9	35.2
Wood Panels	National Carbon Machines	1	571.0	566.5	567.3	15.5	15.6	15.6	37.5	34.5	35.5	569.0	568.4	568.3	17.7	17.9	18.3	34.4	32.4	31.6
		2	567.0	567.3	567.5	15.7	15.7	15.6	36.2	34.5	34.3	568.6	568.5	568.8	18.3	17.5	15.8	33.8	32.6	34.7
		3	566.5	566.7	567.3	15.9	15.7	15.9	36.5	34.0	36.5	568.5	568.7	568.8	17.2	16.6	16.5	32.6	33.9	34.8
	Atlas Machines	1	567.0	567.3	568.3	15.7	15.7	14.5	36.1	34.5	34.5	569.5	570.1	569.3	20.2	21.1	20.4	36.1	35.6	34.3
		2	566.8	567.2	566.7	15.7	15.7	15.9	35.7	32.0	36.7	568.9	569.1	569.2	14.5	15.0	15.2	37.1	34.8	45.5
Olive Drab																				
Metal Panels	National Carbon Machines	1	582	576	..	8.54	8.78	8.53	28.0	..	29.5	575	577	575	11.1	11.4	11.2	28.0	27.5	30.0
		2	576	580	576	8.54	8.37	8.67	27.5	27.5	26.0	573	576	575	10.4	10.9	10.7	26.0	28.0	30.0
		3	580	583	583	8.78	8.72	8.75	28.0	30.0	30.0	577	577	580	10.7	11.1	11.1	28.0	28.0	32.0
	Atlas Machines	1	576	575	582	8.35	8.68	8.74	27.0	29.5	27.5	580	579	579	11.4	12.1	11.8	39.0	36.0	35.0
		2	576	583	583	8.44	8.49	8.75	36.0	30.0	28.0	580	581	580	10.0	10.6	10.5	35.0	34.0	32.0
Wood Panels	National Carbon Machines	1	575	582	576	8.42	8.86	8.88	27.0	30.0	29.0	576	575	575	11.9	12.33	12.4	31.0	30.0	32.0
		2	575	582	586	8.20	8.89	8.75	27.5	30.0	29.0	575	575	568	10.6	11.54	11.9	28.0	29.0	27.0
		3	576	582	575	8.46	8.86	8.95	28.0	30.0	30.0	575	576	558	11.3	12.38	11.9	29.0	30.0	26.0
	Atlas Machines	1	571	..	577	7.95	..	8.79	26.0	..	28.0	579	..	579	12.5	..	13.3	38.0	..	40.0
		2	569	583	576	8.38	8.49	8.79	27.5	27.5	30.0	574	583	576	10.38	9.56	10.5	31.0	30.0	34.0
Earth Brown																				
Metal Panels	National Carbon Machines	1	583	580	584	8.01	7.93	7.73	22.1	22.1	23.0	..	572	587	..	8.65	8.76	..	29.0	32.2
		2	584	586	588	7.99	7.67	7.41	20.0	21.0	21.0	583	584	583	8.44	9.77	8.75	21.8	21.3	23.0
		3	583	..	..	7.79	..	..	22.2	..	..	581	..	..	8.99	..	..	24.1	..	..
	Atlas Machines	1	583	586	589	7.77	7.82	7.48	21.0	23.8	27.8	580	573	579	9.22	9.97	9.20	32.0	34.1	33.1
		2	582	583	583	7.78	7.94	7.92	27.8	21.9	23.0	581	581	581	8.24	8.95	9.01	29.3	27.7	28.1
Wood Panels	National Carbon Machines	1	593	586	583	6.87	7.63	7.33	23.0	23.0	26.8	582	582	581	9.54	9.25	9.69	26.1	26.1	25.0
		2	584	582	582	7.64	7.72	7.30	24.2	22.1	24.0	575	582	582	9.17	9.15	9.19	27.3	21.9	21.8
		3	583	583	..	7.64	7.44	..	24.8	22.9	..	581	581	..	9.79	9.66	..	25.7	25.0	..
	Atlas Machines	1	582	584	587	7.47	7.39	7.54	25.0	22.0	21.0	581	581.2	581	10.22	10.08	9.76	35.1	35.5	36.3
		2	582	582	582	7 54	7.6	7.41	24.0	24.0	27.0	585	581	581	8.81	8.68	8.47	31.0	29.2	29.2

[a] D = by Dip Method; B = by Brush Method; S = by Spray Method.
[b] Dominant wave length.

(Continued on next page)

TABLE III.—DEVELOPMENT OF TEST METHOD—RESULTS OF 300 HR. OF ACCELERATED WEATHERING ON PAINT FINISHES

			Original Finish[a]									Finish After 300 Hours[a]								
			λD[b]			Relative Brightness, per cent			Purity, per cent			λD[b]			Relative Brightness, per cent			Purity, per cent		
			D	B	S	D	B	S	D	B	S	D	B	S	D	B	S	D	B	S
Desert Sand																				
Metal Panels	National Carbon Machines	1	590	618	589	28.71	28.5	28.2	31.9	40.5	34.4	588	588	589	28.83	31.1	30.3	28.2	25.9	26.0
		2	588	589	589	29.34	28.7	28.0	33.9	34.0	34.5	585.2	589	589	30.17	30.7	29.8	24.0	25.8	26.0
		3	590	589	589	28.81	28.8	28.0	32.9	33.1	34.3	589	589	588	29.53	30.4	29.8	26.5	25.9	26.0
	Atlas Machines	1	590	587	586	28.88	28.5	28.4	33.0	34.0	35.0	587	587	588	28.77	30.1	28.6	30.9	27.9	29.0
		2	588	590	589	28.85	28.9	27.7	33.7	32.0	34.3	599	589	589	24.91	28.2	27.6	29.0	30.0	30.3
Wood Panels	National Carbon Machines	1	590	589	589	29.00	28.8	28.1	36.5	34.0	34.0	588	588	590	31.10	32.4	31.8	25.0	24.0	25.1
		2	590	589	588	28.98	29.2	28.0	32.2	34.0	34.5	589	589	589	30.55	30.3	29.6	25.0	25.9	24.3
		3	588	589	589	28.89	29.0	27.5	37.0	34.3	34.1	584	593	589	31.33	30.0	30.5	23.0	25.9	25.0
	Atlas Machines	1	589	589	589	29.10	28.8	27.9	34.3	34.0	34.3	586	585	560	32.87	35.0	35.2	28.0	25.0	20.0
		2	589	589	589	29.21	28.7	27.9	34.0	34.0	34.3	590	589	589	27.07	27.4	27.2	29.0	32.0	32.0
White																				
Metal Panels	National Carbon Machines	1	572.9	..	..	77.1	..	..	3.0	..	..	573.2	..	..	69.8	..	..	8.1	..	..
		2	500.0	..	..	77.1	..	..	0.5	..	..	572.0	..	..	72.0	..	..	5.0	..	..
		3	580.5	..	..	76.4	..	..	2.6	..	..	571.5	..	..	71.6	..	..	4.5	..	..
	Atlas Machines	1	576.2	..	..	76.0	..	..	5.7	..	..	574.0	..	..	68.5	..	..	11.3	..	..
		2	574.4	..	..	75.6	..	..	2.7	..	..	573.9	..	..	67.6	..	..	8.0	..	..
Wood Panels	National Carbon Machines	1	571.3	..	..	76.9	..	..	2.1	..	..	567.4	..	..	73.7	..	..	2.4	..	..
		2	500.0	..	..	76.2	..	..	0.5	..	..	590.0	..	..	73.4	..	..	3.0	..	..
		3	571.6	..	..	75.8	..	..	2.2	..	..	564.8	..	..	73.1	..	..	2.0	..	..
	Atlas Machines	1	572.2	..	..	76.9	..	..	2.3	..	..	573.9	..	..	69.3	..	..	11.1	..	..
		2	569.9	..	..	76.7	..	..	1.8	..	..	570.4	..	..	72.0	..	..	4.2	..	..
Black																				
Metal Panels	National Carbon Machines	1	480	..	..	37.6	..	..	0.04	..	..	480	..	..	32.9	..	..	0.05	..	..
		2	470	..	..	37.3	..	..	0.02	..	..	474	..	..	33.5	..	..	0.03	..	..
		3	470	..	..	37.4	..	..	0.02	..	..	484	..	..	33.5	..	..	0.04	..	..
	Atlas Machines	1	470	..	..	37.6	..	..	0.03	..	..	400	..	..	30.0	..	..	0.03	..	..
		2	465	..	..	38.2	..	..	0.03	..	..	482	..	..	34.7	..	..	0.03	..	..
Wood Panels	National Carbon Machines	1	482	..	..	40.0	..	..	0.03	..	..	480	..	..	34.3	..	..	0.05	..	..
		2	480	..	..	36.5	..	..	0.02	..	..	480	..	..	31.4	..	..	0.03	..	..
		3	478	..	..	36.4	..	..	0.02	..	..	440	..	..	35.1	..	..	0.03	..	..
	Atlas Machines	1	470	..	..	37.4	..	..	0.02	..	..	400	..	..	30.0	..	..	0.01	..	..
		2	486	..	..	38.7	..	..	0.02	..	..	480	..	..	33.1	..	..	0.04	..	..
Haze Gray																				
Metal Panels	National Carbon Machines	1	481.3	..	..	28.0	..	..	18.8	..	..	490.0	..	..	33.1	..	..	4.5	..	..
		2	481.5	..	..	28.2	..	..	18.5	..	..	485.6	..	..	32.4	..	..	8.0	..	..
		3	481.5	..	..	28.2	..	..	18.5	..	..	486.4	..	..	33.3	..	..	6.8	..	..
	Atlas Machines	1	481.5	..	..	28.3	..	..	18.2	..	..	484.5	..	..	28.7	..	..	11.3	..	..
		2	481.5	..	..	28.3	..	..	18.5	..	..	483.7	..	..	28.5	..	..	1.1	..	..
Wood Panels	National Carbon Machines	1	481.5	..	..	28.6	..	..	18.2	..	..	485.7	..	..	36.1	..	..	5.8	..	..
		2	481.5	..	..	28.7	..	..	18.2	..	..	484.9	..	..	34.4	..	..	7.2	..	..
		3	481.5	..	..	28.7	..	..	18.2	..	..	484.4	..	..	36.5	..	..	6.7	..	..
	Atlas Machines	1	481.5	..	..	28.6	..	..	18.1	..	..	511.0	..	..	39.0	..	..	1.3	..	..
		2	481.5	..	..	28.8	..	..	17.8	..	..	490.8	..	..	36.4	..	..	2.6	..	..
Sea Blue																				
Metal Panels	National Carbon Machines	1	480.0	..	..	4.4	..	..	18.0	..	..	485.4	..	..	8.5	..	..	11.6	..	..
		2	480.2	..	..	4.5	..	..	17.3	..	..	485.1	..	..	8.4	..	..	10.1	..	..
		3	480.0	..	..	4.5	..	..	17.5	..	..	480.4	..	..	8.8	..	..	25.9	..	..
	Atlas Machines	1	480.5	..	..	4.5	..	..	17.7	..	..	483.5	..	..	8.4	..	..	11.7	..	..
		2	480.1	..	..	4.5	..	..	17.8	..	..	485.3	..	..	8.2	..	..	9.2	..	..
Wood Panels	National Carbon Machines	1	480.3	..	..	4.4	..	..	17.7	..	..	483.9	..	..	8.7	..	..	11.3	..	..
		2	480.2	..	..	4.4	..	..	17.5	..	..	484.1	..	..	8.6	..	..	10.7	..	..
		3	480.2	..	..	4.5	..	..	17.5	..	..	484.9	..	..	9.3	..	..	10.0	..	..
	Atlas Machines	1	480.5	..	..	4.5	..	..	17.2	..	..	480.2	..	..	4.5	..	..	17.2	..	..
		2	481.0	..	..	4.4	..	..	18.0	..	..	496.5	..	..	9.1	..	..	2.1	..	..

[a] D = by Dip Method; B = by Brush Method; S = by Spray Method.
[b] Dominant wave length.

(Continued on next page)

[a] D = by Dip Method; B = by Brush Method; S = by Spray Method.
[b] Dominant wave length.

(Continued on next page)

TABLE III.—DEVELOPMENT OF TEST METHOD—RESULTS OF 300 HR. OF ACCELERATED WEATHERING ON PAINT FINISHES (Concluded).

			Original Finish[a]									Finish After 300 Hours[a]								
			λD[b]			Relative Brightness, per cent			Purity, per cent			λD[b]			Relative Brightness, per cent			Purity, per cent		
			D	B	S	D	B	S	D	B	S	D	B	S	D	B	S	D	B	S
DULL RED																				
Metal Panels	National Carbon Machines	1	602	..	..	9.77	..	..	40.2	..	..	601	..	..	12.29	..	..	38.0	..	..
		2	602	..	..	9.86	..	..	41.0	..	..	600	..	..	11.80	..	..	36.0	..	..
		3	601.2	..	..	9.84	..	..	40.7	..	..	600	..	..	12.25	..	..	35.0	..	..
	Atlas Machines	1	699.8	..	..	9.69	..	..	40.2	..	..	598	..	..	11.96	..	..	41.9	..	..
		2	600.1	..	..	9.94	..	..	40.6	..	..	600	..	..	10.23	..	..	42.0	..	..
Wood Panels	National Carbon Machines	1	601.2	..	..	9.80	..	..	41.2	..	..	598	..	..	12.19	..	..	42.0	..	..
		2	601.2	..	..	9.62	..	..	42.0	..	..	602	..	..	11.31	..	..	36.3	..	..
		3	601.1	..	..	9.72	..	..	41.6	..	..	601	..	..	11.02	..	..	38.0	..	..
	Atlas Machines	1	601.1	..	..	9.68	..	..	41.8	..	..	598	..	..	12.58	..	..	42.0	..	..
		2	601.8	..	..	9.63	..	..	41.0	..	..	600	..	..	10.56	..	..	41.0	..	..
SAND																				
Metal Panels	National Carbon Machines	1	580.3	..	..	41.1	..	..	40.4	..	..	580.5	..	..	41.5	..	..	33.9	..	..
		2	580.4	..	..	41.5	..	..	40.7	..	..	580.6	..	..	43.3	..	..	33.2	..	..
		3	578.5	..	..	41.7	..	..	43.3	..	..	580.6	..	..	43.0	..	..	33.2	..	..
	Atlas Machines	1	580.3	..	..	41.7	..	..	40.7	..	..	580.2	..	..	40.9	..	..	38.2	..	..
		2	580.5	..	..	41.7	..	..	40.6	..	..	580.6	..	..	40.2	..	..	40.6	..	..
Wood Panels	National Carbon Machines	1	580.3	..	..	41.4	..	..	40.6	..	..	580.6	..	..	43.1	..	..	33.1	..	..
		2	580.4	..	..	41.6	..	..	40.7	..	..	580.4	..	..	43.1	..	..	34.8	..	..
		3	580.4	..	..	41.7	..	..	40.7	..	..	580.5	..	..	43.6	..	..	32.6	..	..
	Atlas Machines	1	580.3	..	..	41.6	..	..	40.8	..	..	579.7	..	..	44.6	..	..	31.9	..	..
		2	580.5	..	..	40.6	..	..	39.6	..	..	580.2	..	..	42.0	..	..	40.7	..	..
EARTH YELLOW																				
Metal Panels	National Carbon Machines	1	583.4	..	..	31.2	..	..	51.5	..	..	581.4	..	..	31.2	..	..	45.6	..	..
		2	583.3	..	..	31.3	..	..	50.8	..	..	584.4	..	..	32.3	..	..	41.2	..	..
		3	583.3	..	..	31.4	..	..	52.0	..	..	584.2	..	..	32.2	..	..	42.2	..	..
	Atlas Machines	1	583.6	..	..	31.3	..	..	51.0	..	..	583.6	..	..	32.1	..	..	44.9	..	..
		2	583.6	..	..	31.5	..	..	51.8	..	..	581.0	..	..	29.9	..	..	51.6	..	..
Wood Panels	National Carbon Machines	1	583.7	..	..	31.3	..	..	51.0	..	..	584.1	..	..	31.3	..	..	44.2	..	..
		2	583.0	..	..	30.8	..	..	50.5	..	..	583.9	..	..	31.4	..	..	45.6	..	..
		3	583.7	..	..	31.4	..	..	52.1	..	..	583.7	..	..	31.2	..	..	47.9	..	..
	Atlas Machines	1	583.8	..	..	31.3	..	..	51.2	..	..	582.9	..	..	33.9	..	..	41.5	..	..
		2	583.8	..	..	31.5	..	..	50.7	..	..	586.1	..	..	29.7	..	..	50.5	..	..
SKY GRAY																				
Metal Panels	National Carbon Machines	1	570.4	..	..	40.2	..	..	21.3	..	..	571.4	..	..	41.0	..	..	17.0	..	..
		2	571.2	..	..	40.1	..	..	20.7	..	..	571.5	..	..	40.4	..	..	16.7	..	..
		3	570.9	..	..	40.4	..	..	21.3	..	..	572.3	..	..	40.5	..	..	18.4	..	..
	Atlas Machines	1	570.2	..	..	40.3	..	..	20.5	..	..	572.2	..	..	40.2	..	..	18.6	..	..
		2	570.1	..	..	40.3	..	..	20.4	..	..	571.8	..	..	37.8	..	..	20.3	..	..
Wood Panels	National Carbon Machines	1	574.2	..	..	40.2	..	..	17.4	..	..	571.4	..	..	41.2	..	..	16.0	..	..
		2	570.2	..	..	40.0	..	..	20.9	..	..	571.2	..	..	42.7	..	..	14.3	..	..
		3	569.9	..	..	40.1	..	..	21.0	..	..	571.5	..	..	40.7	..	..	17.0	..	..
	Atlas Machines	1	570.5	..	..	40.1	..	..	21.4	..	..	573.2	..	..	44.2	..	..	17.2	..	..
		2	570.2	..	..	40.1	..	..	21.2	..	..	571.7	..	..	37.9	..	..	20.2	..	..

[a] D = by Dip Method; B = by Brush Method; S = by Spray Method.
[b] Dominant wave length.

TABLE IV.—COLOR CHANGE DUE TO 300 HR. ACCELERATED WEATHERING, PER CENT (*Continued on p. 39*)

Colors	Metal															
	Dip					Brush					Spray					
	National			Atlas		National			Atlas		National			Atlas		
	No. 1	No. 2	No. 3	No. 1	No. 2	No. 1	No. 2	No. 3	No. 1	No. 2	No. 1	No. 2	No. 3	No. 1	No. 2	
Dominant Wave Length, λD																
Olive drab	− 1.20	− 0.52	− 0.52	0.70	0.70	0.17	− 0.70	− 1.03	0.70	− 0.34	..	− 0.17	− 0.52	− 0.52	− 0.52	
Light green	1.44	1.75	1.46	1.66	0.35	0.26	1.06	0.78	0.18	0.65	1.41	0.37	1.46	1.46	1.20	
Desert sand	− 0.30	− 0.50	− 0.16	− 0.50	1.87	− 4.90	0	0	0	− 0.17	0	0	− 0.17	0.34	0	
Green	0.55	1.50	1.81	0.16	1.60	1.0	1.8	2.4	1.4	0.6	3.0	3.0	3.0	2.0	0.8	
Dark green	0.01	− 0.50	0.93	0.55	1.19	1.0	1.1	2.0	0.9	0.3	0.3	0.4	0.7	1.0	− 0.6	
Relative Brightness, per cent																
Olive drab	30.4	21.9	21.7	36.6	18.4	29.6	29.9	27.5	39.3	24.8	31.6	23.4	26.3	35.4	20.0	
Light green	25.1	6.3	6.8	6.9	6.7	7.0	9.4	3.6	13.3	− 5.7	8.8	6.9	10.8	− 5.6	− 8.1	
Desert sand	0.4	2.8	2.5	0.38	−13.6	9.5	7.0	5.5	5.6	− 2.4	7.5	6.4	6.4	0.7	− 0.36	
Green	21.3	24.3	29.6	2.8	− 1.4	15.8	21.5	27.3	6.0	4.5	25.2	22.8	60.0	7.5	0	
Dark green	52.5	54.2	48.0	34.2	30.0	28.4	32.6	33.4	23.0	16.7	13.6	26.0	28.7	25.0	27.4	
Purity, per cent																
Olive drab	0	− 5.4	0	44.5	− 2.8	− 6.8	7.7	− 6.7	34.5	21.4	..	9.0	6.6	18.6	6.7	
Light green	4.3	1.9	− 0.3	9.0	2.9	− 6.8	− 3.3	−10.5	10.4	− 1.1	− 6.3	− 6.0	− 0.6	10.2	6.6	
Desert sand	−11.6	−29.1	−19.4	− 6.3	13.9	−36.1	−24.0	−21.7	−17.9	− 6.3	−24.5	−24.5	−24.9	−17.1	−11.7	
Green	−26.6	−25.0	−26.6	−17.8	−12.3	−20.0	−20.0	−23.0	−23.0	−17.0	−18.0	−18.0	−18.0	−22.0	−13.0	
Dark green	−12.0	29.4	11.6	8.3	15.3	16.0	26.4	39.3	4.5	− 3.7	10.0	11.5	14.0	24.0	20.3	

an analysis of rank, in which the color with the smallest change was given a value of 1 and the next larger change a value of 2. This analysis of rank is shown as Table V. The average rank for each color for the five machines was obtained. If the rank of a color in a machine did not differ from the average by more than one number, that machine treated the color equal to an average machine, and this was considered as a correlation. The total of such correlations and the percentage of correlation of all colors in all machines was calculated, and is shown in Table VI for each color factor, method of preparation, and type of panel. This table shows that the colors exposed in the five machines have the same general relationship to each other after exposure in 87 to 93 per cent of the cases. This means that the color changing the least in one machine changed the least in all machines, and that the color changing the most in one machine changed the most in all machines, regardless of the method of preparation or type of panel used. In addition, although no two machines gave identical exposure results in this portion of the investigation, the exposure results for each machine were consistent for that machine, in that the machine gave either a more or a less severe exposure on all colors tested in that machine. Therefore, if the five machines could be adjusted so that the exposure results for one color would be equal in all machines, the exposure results for any other color would be equal in all machines.

Method of Application.—The desired method of application is one which will least affect the exposure results. It was necessary to determine the variation of results caused by each method of application. The percentage of average deviation between the results of the five panels of each color was determined for each method of application. The results obtained from each color were totaled and averaged so that a composite percentage of deviation was available for each method of application and each type of panel. This is shown in Table VII.

For convenience, the composite average percentage of deviation is shown in Table VIII. This comparison shows that the spray method of application gives the best reproducibility on the unweathered wood and metal panels, whereas the dip application gives the poorest. After exposure in the weathering machines, however, the dip method of application shows the least increase in deviation between the before and after results. This means that the dip method of application furnished panels that measured the effects of weathering

TABLE V.—ANALYSIS BY RANK.

Colors	Metal																	
	Dip						Brush						Spray					
	National			Atlas		Avg.	National			Atlas		Avg.	National			Atlas		Avg.
	No. 1	No. 2	No. 3	No. 1	No. 2	Rank	No. 1	No. 2	No. 3	No. 1	No. 2	Rank	No. 1	No. 2	No. 3	No. 1	No. 2	Rank
Dominant Wave Length, λD																		
Olive drab	4	3	2	4	2	3	1	2	3	3	3	2	..	2	3	2	2	2
Light green	5	5	4	5	1	5	2	3	2	2	5	3	3	3	2	4	5	4
Desert sand	2	1.5	1	2	5	1.5	5	1	1	1	1	1	1	1	1	1	1	1
Green	3	4	5	1	4	4	3.5	5	5	5	4	5	4	5	5	5	4	5
Dark green	1	1.5	3	3	3	1.5	3.5	4	4	4	2	4	2	4	4	3	3	3
Conformity, per cent	84	..	..	..	..	..	84	..	..	..	..	..	95	..	..	..	..	..
Relative Brightness, per cent																		
Olive drab	4	3	3	5	4	4	5	4	4	5	5	5	5	4	3	5	4	5
Light green	3	2	2	3	2	2	1	2	1	3	3	2	2	2	2	2	3	2
Desert sand	1	1	1	1	3	1	2	1	2	1	1	1	1	1	1	1	2	1
Green	2	4	4	2	1	3	3	3	3	2	2	3	4	3	5	3	1	3
Dark green	5	5	5	4	5	5	4	5	5	4	4	4	3	5	4	4	5	4
Conformity, per cent	92	..	..	..	..	..	100	..	..	..	..	..	92	..	..	..	..	..
Purity, per cent																		
Olive drab	1	2	1	5	1	1.5	1.5	2	1	5	5	2	..	3	2	3	2	2
Light green	2	1	2	3	2	1.5	1.5	1	2	2	1	1	1	1	1	1	1	1
Desert sand	3	4	4	1	4	3	5	4	3	3	3	4	4	5	5	2	3	4
Green	5	3	5	4	3	5	4	3	4	4	4	5	3	4	4	4	4	4
Dark green	4	5	3	2	5	4	3	5	5	1	2	3	2	2	3	5	5	2
Conformity, per cent	84	..	..	..	..	..	76	..	..	..	..	..	88	..	..	..	..	..

TABLE IV.—AMOUNT OF CHANGE IN COLOR DUE TO 300 HR. ACCELERATED WEATHERING (*Concluded*).

Wood															Colors
Dip					Brush					Spray					
National			Atlas		National			Atlas		National			Atlas		
No. 1	No. 2	No. 3	No. 1	No. 2	No. 1	No. 2	No. 3	No. 1	No. 2	No. 1	No. 2	No. 3	No. 1	No. 2	
DOMINANT WAVE LENGTH, λD															
0.17	0	− 0.17	1.40	0.88	− 1.20	− 1.20	− 1.00	..	0	− 0.17	− 3.08	− 2.95	0.34	0	Olive drab
− 0.35	0.28	0.35	0.44	0.37	0.33	0.21	0.35	0.49	0.33	0.17	0.22	0.26	0.17	0.44	Light green
− 0.30	− 0.10	0.69	− 0.50	0.17	− 0.17	0.17	0.68	− 0.68	0	0.17	0	0	− 4.90	0	Desert sand
1.5	2.0	1.8	4.8	4.5	1.1	1.1	2.0	7.0	5.2	1.5	0.7	1.8	4.8	4.8	Green
1.0	0.7	1.5	2.9	3.0	1.7	1.3	2.3	1.6	3.4	1.5	1.8	1.5	3.4	3.1	Dark green
RELATIVE BRIGHTNESS, PER CENT															
41.5	29.3	33.6	57.2	23.8	39.2	29.3	39.5	..	13.0	39.5	35.5	32.5	51.3	19.4	Olive drab
14.1	16.5	8.1	28.6	− 7.6	14.7	11.4	5.7	34.3	− 4.4	17.3	1.2	3.7	40.6	− 4.4	Light green
7.2	5.4	8.4	12.9	− 7.6	12.5	3.8	3.5	21.5	− 4.5	13.2	5.7	10.9	26.1	− 2.5	Desert sand
30.0	33.0	33.0	51.0	40.4	30.0	30.0	38.0	58.0	53.0	33.0	25.0	45.0	50.0	48.0	Green
66.1	67.5	70.0	89.0	76.0	59.4	41.8	62.0	81.0	67.5	50.6	45.9	53.4	72.6	61.6	Dark green
PURITY, PER CENT															
11.1	1.8	3.6	46.2	12.7	0	− 3.3	0	..	9.1	10.5	− 6.8	−13.3	42.8	13.3	Olive drab
− 8.1	− 6.6	−10.8	0	3.8	6.1	− 5.4	− 0.2	3.1	8.7	−10.8	1.1	− 4.5	− 0.5	24.1	Light green
−31.5	−22.4	−37.7	−18.4	−14.6	−29.4	−23.8	−24.4	26.4	− 5.9	−26.3	−29.7	−26.7	−41.8	− 6.7	Desert sand
−28.0	−16.0	−37.0	−12.0	−13.0	−21.0	−27.0	−27.0	18.0	−10.0	−23.0	−20.0	−24.0	− 7.0	−16.0	Green
9.2	− 1.6	23.3	66.6	65.6	40.4	23.8	47.0	51.8	93.1	45.4	34.9	48.6	32.3	73.5	Dark green

more accurately, since the changes in color resulting from weathering are less affected by this method of application.

Type of Panel.—In Table VIII the variations resulting from the effects of the machine on the type of panel are evident. Although the unweathered wood panels showed less variation for all methods of application than did the metal panels, after weathering, the wood panels showed greater variation for all methods of application. This increase in variation after weathering shows that the wood panels contribute to a substantial degree to the difficulty of obtaining reproducible results in weathering machines. It was evident that the use of wood panels would be unsatisfactory.

Table VI shows that after exposure, the relationship of colors to each other was equal on wood and metal panels. The type of panel, therefore, had not altered the relationship of one color to another. This fact means that the results obtained using metal panels would be as valid as those obtained using wood panels, and would have the additional advantage of supplying more reliable results. In other words, the change in color would be caused by the machine and not by the type of panel.

Rest Period.—The factor of "rest periods" had received a cursory study in this investigation to determine whether exposure for 8 hr. a day or 20 hr. a day altered the results. This item is of importance because of the different operating procedures of different laboratories. In addition, the days on which the exposures were started were also noted to determine the relationship of the week-end rest period and its possible effects. The information obtained in regard to rest periods was not sufficiently comprehensive to determine definitely what the effects were. In general, however, on the basis of the limited data available, it appeared that changes in color of the test samples were due to the total number of hours of actual exposure and were not measurably affected by the variation in the number of hours of daily exposure nor by other interruptions in the exposure schedule.

Summary of Findings:

On the basis of the data amassed and examined, it was found that reproducible results could be obtained in either type of machine used. It was established that the same general results were obtained whether metal or wood panels were used, but that the metal panels gave more reproducible results; and furthermore, that when primed metal panels were used, a dip application of the paint coating resulted in smaller variation in results than that caused by brush or spray application.

Finally, it was established that, with

TABLE V.—ANALYSIS BY RANK (*Continued*).

Wood																		Colors
Dip						Brush						Spray						
National			Atlas		Avg.	National			Atlas		Avg.	National			Atlas		Avg.	
No. 1	No. 2	No. 3	No. 1	No. 2	Rank	No. 1	No. 2	No. 3	No. 1	No. 2	Rank	No. 1	No. 2	No. 3	No. 1	No. 2	Rank	
DOMINANT WAVE LENGTH, λD																		
1	1	1	3	3	1	4	4	3	..	1.5	3	2	5	5	2	1.5	3	Olive drab
3	2	2	1	2	2	2	2	1	1	3	2	2	2	2	1	3	1	Light green
2	3	3	2	1	3	1	1	2	2	1.5	1	2	1	1	5	1.5	2	Desert sand
5	5	5	5	5	5	3	3	4	4	5	4	4.5	3	4	4	6	5	Green
4	4	4	4	4	4	5	5	5	3	4	5	4.5	4	3	3	4	4	Dark green
88	..	..	..	..	..	92	..	..	..	..	..	80	..	..	..	..	..	Conformity, per cent
RELATIVE BRIGHTNESS, PER CENT																		
4	3	4	4	3	4	4	3	4	..	3	4	4	4	3	4	3	4	Olive drab
2	2	1	2	1.5	2	2	2	2	2	1	2	2	1	1	2	2	2	Light green
1	1	2	1	1.5	1	1	1	1	1	2	1	1	2	2	1	1	1	Desert sand
3	4	3	3	4	3	3	4	3	3	4	3	3	3	4	3	4	3	Green
5	5	5	5	5	5	5	5	5	4	5	5	5	5	5	5	5	5	Dark green
100	..	..	..	..	..	100	..	..	..	..	..	100	..	..	..	..	..	Conformity, per cent
PURITY, PER CENT																		
3	2	1	4	2	2	1	1	1	..	3	1	1	2	2	5	3	2	Olive drab
1	3	2	1	1	1	2	2	2	1	2	2	2	1	1	1	4	1	Light green
5	5	5	3	4	5	4	3.5	3	3	1	3	4	4	4	4	1	4	Desert sand
4	4	4	2	3	4	3	5	4	2	4	4	3	3	3	2	2	3	Green
2	1	3	5	5	3	5	3.5	5	4	5	5	5	5	5	3	5	5	Dark green
80	..	..	..	..	..	84	..	..	..	..	..	88	..	..	..	..	..	Conformity, per cent

TABLE VI.—PERCENTAGE OF CORRELATION OF COLOR.

Method of Application	Dominant Wave Length, λD		Relative Brightness, per cent		Purity, per cent		Average	
	Metal Panels	Wood Panels	Metal Panels	Wood Panels	Metal Panels	Wood Panels	Metal Panels	Wood Panels
Dip	84	88	92	100	84	80	87	89
Brush	84	92	100	100	76	84	87	92
Spray	95	80	92	100	88	88	92	89

weathering conditions equal in different machines, for any color the changes would be the same in different machines.

Correlation of the Two Types of Weathering Machines

Procedure:

Since there was no machine available for use as a standard against which all the other machines could have been compared, this possibility as a test method was discarded. The alternative chosen involved the exposure of identical paint samples in all machines tested, for identical periods of total time. The change in color as a result of the exposure in the machines was calculated as delta E, and the delta E's obtained in each machine on each panel were compared. The statistical comparison was compiled by using an analysis of variance (see Appendix).

Metal panels, measuring 3 by 5 in., were primed with a zinc chromate primer and were allowed to age under normal room conditions. They were then dipped in light green paint, specification T-1215, dried under normal room temperature, and allowed to age for two weeks. Spectrophotometric curves were prepared for each panel prior to exposure in the weathering machine. The National machines were then operated on their normal cycle for 300 hr., at the expiration of which time spectrophotometric curves were again made for each of the panels exposed.

Four separate tests of 300 hr. each were run on the Atlas machines, each with a different cycling cam installed. Cams used were the 17-3, 51-9, 102-18, and 68-12. Choice of cams to be tested was restricted to those which would give approximately the same water to light ratio as does the standard cycle of the National machines.

In all tests, the machines were held to a temperature of 155 ± 5 F. as measured by black panel thermometers,

TABLE VII.—PANEL REPRODUCIBILITY BY METHOD OF APPLICATION AND TYPE OF PANEL.

Colors	Before Weathering						After Weathering					
	Metal			Wood			Metal			Wood		
	Dip	Brush	Spray	Dip	Brush	Spray	Dip	Brush	Spray	Dip	Brush	Spray
Dominant Wave Length, λD												
Dark green	0.36	0.01	0.42	0.17	0.39	0.28	0.25	0.39	0.42	0.79	0.73	0.63
Desert sand	0.17	1.57	0.16	0.11	0.05	0	0.32	0.12	0.08	0.37	0.31	1.60
Light green	0.68	0.28	0.35	0.24	0.06	0.07	0.43	0.35	0.49	0.49	0.90	0.81
Green	0.22	0.17	0.13	0.03	0.10	0.01	0.39	0.54	0.73	1.28	2.18	1.60
Olive drab	0.42	0.54	0.25	0.45	0.06	0.55	0.41	0.28	0.39	0.24	0.72	1.14
Average deviation for all colors, per cent	0.370	0.514	0.262	0.20	0.13	0.18	0.360	0.336	0.422	0.63	0.97	1.28
Relative Brightness, per cent												
Dark green	2.20	0.81	0.27	0.81	0	0.27	6.48	5.11	3.56	4.21	5.85	5.42
Desert sand	0.59	0.49	0.64	6.44	0.55	0.50	4.95	2.52	3.09	4.65	6.39	6.74
Light green	3.31	1.51	0.50	0.51	0.13	2.58	0.51	0.13	2.58	7.85	8.53	9.71
Green	0.59	1.05	0.45	0	0.61	0.61	10.00	6.36	12.70	4.6	7.13	6.27
Olive drab	1.26	1.65	0.81	2.78	1.33	0.75	3.92	3.75	3.24	6.02	0.68	5.68
Average deviation for all colors, per cent	1.590	1.102	0.534	2.11	0.52	0.94	3.972	3.594	5.034	5.47	5.72	6.76
Purity, per cent												
Dark green	12.21	3.46	9.15	2.62	6.72	4.50	5.60	12.95	10.00	1.81	17.00	13.85
Desert sand	1.75	6.62	0.58	6.71	0.35	0.47	6.22	5.69	6.41	7.68	16.58	10.68
Light green	2.75	2.35	2.17	1.32	2.24	2.48	4.22	2.94	6.00	4.13	3.18	2.98
Green	3.71	1.58	1.15	4.57	1.97	0.72	3.12	2.00	2.13	15.40	14.30	5.58
Olive drab	7.76	4.40	3.08	2.06	2.52	2.19	14.80	11.20	4.55	8.44	0.94	13.30
Average deviation for all colors, per cent	5.636	3.682	3.226	3.456	2.760	2.072	6.792	6.956	5.818	7.492	10.400	9.078
Average deviation for all colors and three color functions, per cent	2.53	1.77	1.34	1.92	1.14	1.06	3.71	3.63	3.76	4.53	5.69	5.71

TABLE VIII.—COMPOSITE AVERAGE PER CENT DEVIATION IN COLOR DUE TO PANEL AND METHOD OF APPLICATION.

Type of Panel	Method of Application		
	Dip	Brush	Spray
Before Weathering			
Metal	2.53	1.77	1.34
Wood	1.92	1.14	1.06
After Weathering			
Metal	3.71	3.63	3.76
Wood	4.53	5.69	5.71

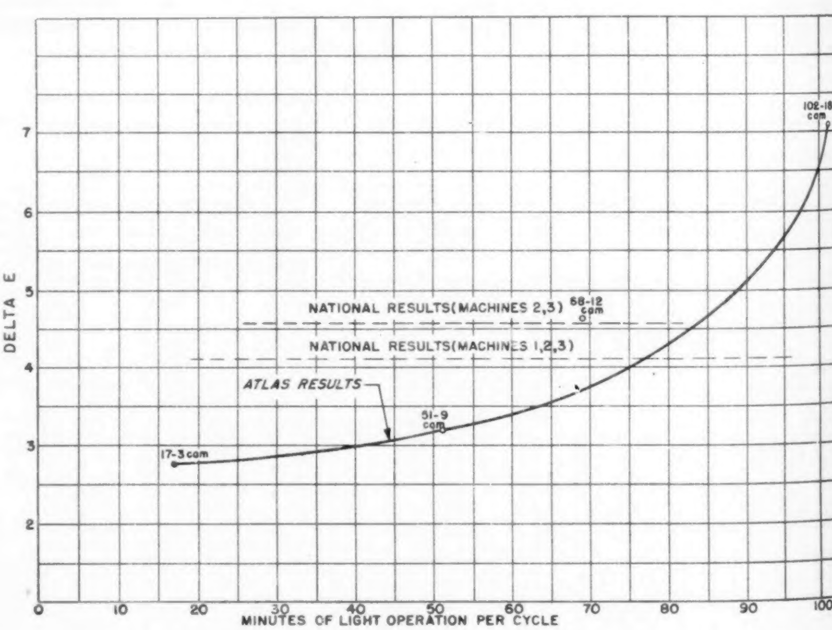

Fig. 4.—Comparison of Delta E Values of National and Atlas Machines.

TABLE IX.—BEFORE AND AFTER WEATHERING FACTORS—LIGHT GREEN.

Weathering Machine	Specimen	Original			300 Hr.			ΔE, Change in Color, per cent
		λD[a]	Relative Brightness, per cent	Purity, per cent	λD[a]	Relative Brightness, per cent	Purity, per cent	
National No. 1	1A.......	567.4	17.83	36.0	569.0	18.23	33.5	3.11
	1B.......	567.0	17.98	35.0	568.8	18.06	34.0	3.34
	1C.......	567.0	17.93	35.0	569.3	18.21	34.0	3.79
	1D.......	567.0	17.87	35.0	568.8	18.23	34.0	3.39
	1E.......	567.0	18.02	33.8	569.0	18.18	33.9	3.41
								(Avg.) 3.41
National No. 2	2A.......	566.8	17.90	34.0	569.5	19.12	32.8	4.59
	2B.......	567.0	18.02	33.9	569.1	18.79	33.4	3.69
	2C.......	567.0	17.96	34.2	569.5	18.82	33.7	4.12
	2D.......	566.9	17.84	34.6	569.5	18.82	34.0	4.44
	2E.......	566.2	17.92	34.2	569.1	19.13	32.5	5.06
								(Avg.) 4.38
National No. 3	3A.......	566.9	17.84	34.5	570.0	18.86	35.9	5.23
	3B.......	567.0	17.90	33.8	570.0	18.41	36.7	4.74
	3C.......	567.3	17.86	35.3	570.0	18.49	36.3	4.04
	3D.......	567.3	17.58	34.5	569.7	18.55	35.5	4.47
	3E.......	567.2	17.58	35.0	570.0	19.02	36.0	4.75
								(Avg.) 4.85
Atlas No. 1—17-3 cam	4A.......	567.5	17.96	35.0	567.7	17.09	35.1	1.36
	4B.......	567.2	18.23	34.8	568.0	17.20	35.0	1.98
	4C.......	567.1	17.92	35.0	568.0	17.22	35.0	1.72
	4D.......	567.1	17.93	35.0	567.8	17.01	35.2	1.44
	4E.......	567.1	17.84	35.0	568.0	16.77	36.0	1.96
								(Avg.) 1.69
Atlas No. 2—17-3 cam	5A.......	567.2	18.06	34.8	570.5	17.97	38.5	4.24
	5B.......	567.2	18.02	34.8	571.2	17.77	38.7	2.95
	5C.......	567.2	18.08	35.5	570.4	18.27	38.7	2.64
	5D.......	567.0	17.87	35.1	570.0	17.94	37.9	4.81
	5E.......	567.3	17.99	35.5	570.1	17.96	38.5	4.37
								(Avg.) 3.80
Atlas No. 1—51-9 cam	6A.......	566.9	17.91	34.5	568.3	16.41	37.3	2.85
	6B.......	567.0	17.91	34.2	568.3	16.52	37.8	2.63
	6C.......	566.9	17.91	34.5	568.2	16.51	36.8	2.67
	6D.......	567.0	18.00	35.0	568.3	16.80	36.6	2.32
	6E.......	567.5	17.99	36.0	568.1	16.56	36.2	2.20
								(Avg.) 2.53
Atlas No. 2—51-9 cam	7A.......	567.0	18.00	34.6	569.0	19.14	35.0	3.73
	7B.......	567.6	17.72	34.5	569.2	19.40	34.2	3.10
	7C.......	567.3	18.07	34.6	569.5	19.84	34.1	4.24
	7D.......	567.3	17.91	35.2	569.3	19.62	34.4	4.28
	7E.......	567.1	17.86	35.0	569.1	19.01	34.1	3.44
								(Avg.) 3.76
Atlas No. 1—102-18 cam	8A.......	567.0	17.95	34.4	568.0	17.27	40.5	3.13
	8B.......	567.2	17.82	34.7	570.6	16.66	50.2	7.86
	8C.......	567.2	17.86	34.6	570.4	16.68	49.8	7.87
	8D.......	567.1	17.90	35.0	569.6	17.18	47.8	8.22
	8E.......	567.1	17.80	35.0	570.2	16.93	48.9	7.75
								(Avg.) 6.97
Atlas No. 2—102-18 cam	9A.......	566.9	17.96	34.5	568.2	17.02	45.5	5.52
	9B.......	566.9	18.00	34.5	571.4	18.84	49.6	8.40
	9C.......	567.0	18.02	34.2	569.2	18.60	44.6	7.76
	9D.......	567.3	17.88	34.5	570.0	18.55	44.6	7.35
	9E.......	567.2	17.73	34.7	570.2	18.02	44.9	6.66
								(Avg.) 7.14
Atlas No. 1—68-12 cam	10A.......	567.0	18.04	34.0	570	18.77	33.2	4.36
	10B.......	567.0	18.04	34.0	570	18.77	33.2	4.36
	10C.......	567.0	18.04	34.0	570	18.37	34.2	4.99
	10D.......	567.0	18.04	34.0	570	18.77	33.2	4.36
	10E.......	567.0	18.04	34.0	570	18.38	33.2	4.62
								(Avg.) 4.52
Atlas No. 2—68-12 cam	11A.......	567.0	18.04	34.0	570	18.30	33.2	4.84
	11B.......	567.0	18.04	34.0	570	18.38	33.2	4.70
	11C.......	567.0	18.04	34.0	570	18.38	33.2	4.62
	11D.......	567.0	18.04	34.0	570	18.38	33.2	4.62
	11E.......	567.0	18.04	34.0	570	18.00	34.2	4.62
								(Avg.) 4.68

[a] Dominant wave length.

TABLE X.—REPRODUCIBILITY OF COLOR AFTER EXPOSURE WITH 68-12 CAM.

	National		Atlas	
	No. 2	No. 3	No. 1	No. 2
Dominant wave length, λD.......	569.5	570.0	570.0	570.0
	569.1	570.0	570.0	570.0
	569.5	570.0	570.0	570.0
	569.5	519.7	570.0	570.0
	569.5	570.0	570.0	570.0
Avg........................	569.4	569.9	570.0	570.0
Relative brightness, per cent......	19.12	18.86	18.77	18.30
	18.79	18.44	18.77	18.38
	18.82	18.49	18.37	18.38
	18.82	18.55	18.77	18.38
	19.13	19.02	18.38	18.00
Avg........................	18.94	18.67	18.61	18.29
Purity, per cent..................	32.8	35.9	33.2	33.2
	33.4	36.7	33.2	33.2
	33.7	36.3	34.2	33.2
	34.0	35.5	33.2	34.2
	32.5	36.0	33.2	33.2
Avg........................	33.3	36.1	33.4	33.4

in accordance with the tested practice developed in the preliminary investigation.

Results:

A complete listing of the before and after weathering values for the three color factors (**5**) and the delta E values (**6**) is given in Table IX.

An analysis of variance[4] was applied, with the dimensionless F value determined for each machine. The F value represents the ratio of deviation caused by the factor in question to the deviation caused by the error inherent in the testing method. The F values were calculated as follows:

[4] See brief discussion of method in Appendix.

Cams Used	F Values				5 per cent Level of Significance
	17-3	51-9	102-18	68-12	
Among Nationals....	7.1	12	1.6	17.90	8.1
Between Atlas.....	37.0	22	15.2	7.06	5.8
National *versus* Atlas.	39.0	35	39.2	9.54	8.1

It was noted that the F value for each of the cams tested for each of the three conditions was greater than the 5 per cent level value, and there was, therefore, a significant difference between machines. In other words, the results obtained in any one of the machines did not necessarily compare with that of any other machine, irrespective of manufacture.

An inspection of the results showed that, with the 68-12 cam, the two Atlas machines furnished results very close to those of two of the National machines. Since the National machine that was lower in the amount of change proved to have an operating temperature 20 F. below that of the other four machines, the erroneous results were caused by different operating conditions and were therefore discarded from this computation.

The F test values after the analysis of variance of the four machines, with the 68-12 cam in the Atlas, showed:

	F Values	5 per cent Level of Significance
Between Nationals......	1.33	8.53
Between Atlas..........	7.93	8.53
National *versus* Atlas....	6.11	8.53

That is, there was no significant difference among the four machines operating in the specified temperature range.

The delta E results for different machines and for each machine have been established as equivalent. It should be remembered, however, that delta E indicates only the magnitude, not the type, of change. Both factors are essential to correlation. The factor of type of change, that is, the weathered values of the three color factors for the five panels in each machine is shown in Table X. It was noted that differences in dominant wave length were so slight as to be measured in tenths of microns; percentage of relative brightness overlapped completely in all cases; and there was but one variation in percentage of purity. Therefore, the type of change in color and the amount of change in color were equivalent in all machines.

Discussion:

The results obtained with the 17-3, 51-9, and 102-18 cams in the Atlas did not correlate with the results obtained with the National machines. A graph was drawn by plotting the delta E values for each cam *versus* the delta E values for the Nationals. The point of intersection indicated the theoretical proper cam for duplicating the results of the Nationals. Since this 78-14 cam (a total of 92 min. for one complete cycle) did not divide exactly into the 1440 min. in a 24-hr. period controlled by the cam, the nearest cam that would give such an exact division was selected. This cam is the 68-12, giving 12 continuous minutes of water operation in every 80 min. of arc operation and providing 18 such complete cycles per 24-hr. period.

This cam furnished results identical with those obtained in the National, if the National in which the operating temperature was found to be 20 F. below the test standard is dropped from consideration. It is believed that the result from the 68-12 cam does not fall exactly on the Atlas performance curve shown in Fig. 4 because the curve was constructed through too few data points.

This work shows that a definite relation exists between exposure results obtained in either machine and the length of time which the panels receive water. In addition, the operating temperature is an important factor in regard to the severity of the exposure. To obtain a standard exposure it will be necessary that these two factors be specified in the operating procedure.

Conclusions:

It is concluded that the results obtained from accelerated weathering in the National Carbon X1a and the Atlas Twin Arc Weatherometers correlate under the following conditions:

(*a*) The paint is dip-applied on primed metal panels.

(*b*) The machines are both operated in accordance with Federal Specification TT-P-141a, modified to control machine temperatures at 155 ± 5 F.

(*c*) The . Atlas Weatherometer is equipped with the 68-12 control cam.

Acknowledgment:

The authors are indebted to N. Dickinson, R. Edenton, and W. Murphy for their assistance in this program. This investigation was conducted under the general supervision of A. W. Van Heuckeroth.

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APPENDIX

An Analysis of Variance

The method used to correlate or attempt to show the difference between the two types of machines or within these machines in their weathering properties is called Analysis of Variance. Briefly, the mathematics concerned are as follows: The hypothesis states that the various column means, in this case, the average E values for the panels in each machine, come from identical normal populations with the same mean and standard deviation. If this hypothesis is true, then the same unknown factors which cause variations among the machines would also cause variations within the machines from panel to panel. The standard deviations for these two variables would then approximate each other. If these standard deviations or means or both can be shown to be different, then the hypothesis fails and it must be rejected. The tests used in the calculations are: the a and b_1 tests to show normality, the L_1 to show similarity of the standard deviations, and F to show similarity of means. The a and b_1 and L_1 tests are applied first, and if the populations are normal and have the same standard deviations, the F test is applied. If this fails the means are different or, in other words, the machines weather different amounts.

The procedure for this determination is covered in many standard books on industrial statistics such as H. A. Freeman's (7). Each of the various tests is described and formulas given for their use and application.

There are two important problems in the use of Analysis of Variance. The first is that the sum of the variances due to the several factors must equal the total variance or the figures do not mean anything and the calculations are incorrect. The

reason for this is simply the fact that the variation inherent in the total experiment must be the sum of the variations of each of the factors studied, plus the variation due to the unallocable factors or the error as it can be called. This is an application of the principle of psychology that the whole must equal the sum of its parts.

The second problem is the choice of which variables should be studied and how the breakdown should be made. As an example, it was found during this weathering experiment that not only were machines and colors affecting the results but the interaction of the two was also an important factor. The interaction factor should not be lumped in with the error. In such a case, replication of panels would enable one to determine the interaction effect. Also many times it is known that one factor in an experiment does not make a significant difference and so its small variance can be lumped in with the error term to make it more significant and better able to show difference in other factors.

The *t* test, which is a specific application of the *F* test, is often used in conjunction with it. If the *F* test shows there is a significant difference among several factors, these factors can be taken two at a time and the *t* test will show if there is a significant difference between them. In this way, the offending factors can be determined and either corrected or taken out of the over-all pictures.

A Laboratory Study of Intake Valve Burning[1]

By Court L. Wolfe[2] and R. S. Spindt[2]

For a number of years there have been isolated reports of intake valve failure. An example of such a valve burned in service is shown in Fig. 1. During the winter of 1945 and 1946, a marked increase in intake valve burning was observed in many gasoline-powered vehicles employed in fleet operation and other heavy-duty service.

The phenomena seemed to occur at about the time when considerable amounts of both stored and catalytically

Fig. 1.—Intake Valve Burned in Service.

cracked gasoline were being released for civilian consumption. It has been proposed that the release of these gasolines may have been responsible for the increase in intake valve burning, but there is not adequate evidence to establish this. The present investigation has been undertaken to study the conditions under which intake valve deposits and intake valve burning might be anticipated and what factors may be involved. Because the work is incomplete and our knowledge of the subject very limited this paper is largely a progress report of the results obtained.

The studies have developed along the following outline:

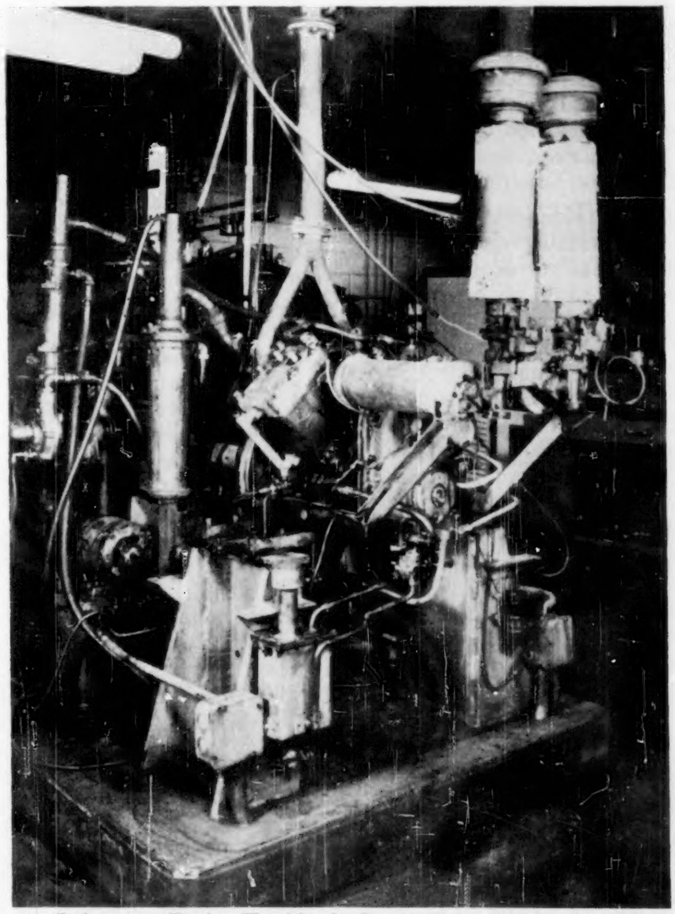

Fig. 2.—Laboratory Engine Used in the Intake Valve Burning Investigation.

1. Exploratory studies of the conditions required to make a valve burn.
2. Effect of fuel type on amount and character of valve fillet deposit and on valve burning.
3. Effect of air-fuel mixture temperature on amount of valve fillet deposit.
4. Effect of engine operating variables on intake valve temperature.

Equipment and Procedures:

A two-cylinder 90-deg. V-type engine especially designed for research purposes was employed during this investigation. A photograph of the installation is shown in Fig. 2. The bore and

[1] Presented at a Symposium on Exhaust Valve Burning held at a meeting of Technical Committee B on Lubricating Oils of A.S.T.M. Committee D-2 on Petroleum Products and Lubricants, Atlantic City, June 28, 1949.

[2] Mellon Institute, Pittsburgh, Pa.

stroke of the unit are respectively $3\frac{1}{8}$ in. and $4\frac{3}{8}$ in. An individual carburetor was installed on each cylinder in order that the amount and type of fuel supplied to each could be controlled independently. In addition, heaters were applied to each induction system to permit control of the incoming air and air-fuel mixture temperature. The usual engine techniques were employed. These included thermocouples for temperature determination, and control of speed, exhaust back pressure, air-fuel ratio, and other engine variables. Figure 3 shows a schematic diagram of the induction system with thermocouples at TC_1, TC_2, TC_3, and TC_4. Heated plugs to simulate the manifold hot spot in an automotive engine, shown at TC_3 directly beneath the carburetor, were later removed because they did not function to collect a deposit as anticipated. The air temperature was measured at TC_4 and the air-fuel mixture temperature at the point TC_1. It is realized that temperatures recorded by these thermocouples may not be accurate in absolute value. However, it is believed that the relative temperatures measured are accurate and can be relied upon as such. The valve thermocouple at TC_2 will be discussed later.

Primary Studies:

The initial exploratory studies were made to find operating conditions which would burn intake valves in the laboratory. In this work no attempt was made to restrict the operating conditions to those found in service because the test engine cannot be compared directly with commercial engines. It was believed, however, that results found with this engine could be used as a guide to the study of intake valve burning under service conditions. These initial studies included operating the engine at various air and air-fuel mixture temperatures, while all other engine conditions were comparable to those found in service. Under these conditions, typical, although light, valve deposits were obtained when using several commercial fuels of a type thought to be responsible for intake valve burning. No evidence of valve burning was found in these tests. A straight-run distillate was also tested; it was found to give relatively little deposit and no indication of valve burning.

Further attempts were made to burn valves by altering mechanical and operating variables. A thermally cracked type 1 fuel was used for these preliminary-studies, because some intake valves were reported to have been burned in service when using a gasoline blend containing large amounts of this distillate. Several tests were therefore made using this fuel and operating under moderate engine conditions. No valve burning was observed in 70 hr., although fairly heavy fillet and face deposits were obtained. During the course of these experiments, the valve timing was varied through a small range in order to alter the amount of blow-back through the intake valve port. It was found that, under this particular set of operating conditions, maximum fillet deposits were obtained by setting the intake valves to open at 12 deg. B.T.D.C. (before top dead center).

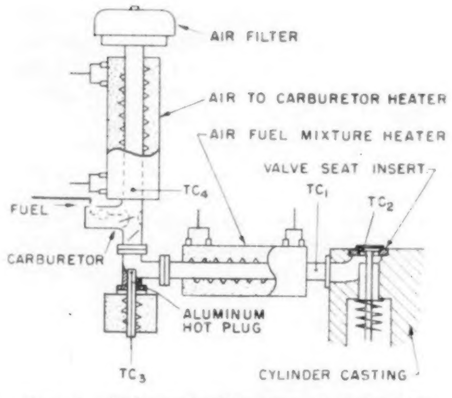

Fig. 3.—Schematic Diagram of Induction System Used in the Valve Burning Investigation. No. 7, 2-Cylinder Test Engine.

Microscopic examination of these valves indicated a possible explanation for the negative results obtained. It was found that, although a heavy face deposit existed, it was rather soft or plastic in character. A valve overlaid with a deposit of this type would not burn because the soft deposit, evidently, tended to heal over immediately any incipient blow-by areas. Further tests indicated that when using a fuel of this type, a better seal is actually formed as the test progresses. It was believed that these valves could be burned if the soft face deposit was baked to a hard brittle material by a change of either operating or mechanical engine conditions.

In an attempt to burn through this face deposit, the exhaust back pressure was increased to 7 in. of mercury, the intake valves were pinned to prevent rotation, and the unit pressure on the valve seat was reduced by installing a lighter spring and increasing the valve seat width to $\frac{1}{2}$ in. The operating procedure was changed to include a cycling test, aimed at producing a thermal shock. These changes did not induce any evidence of burning.

Effect of Fuel Type:

Attempts were then made to burn through the deposit by operating with a straight-run fuel. It was believed that this fuel would induce burning by causing the soft face deposit previously laid down, to bake, become brittle, and gutter when not continuously replenished.

Although valve burning was not obtained during this test, the results were encouraging, since the face deposits were baked to a hard brittle material. It was, therefore, decided to pursue this line of attack and attempt to increase the severity of the test by using a very clean fuel and increasing the operating temperatures to abnormally high values. This series of tests was extended by operating on *isooctane* at elevated jacket and mixture temperatures. The valve was burned by this operation.

The test procedure being employed at this point in the investigation was as follows:

Engine Conditions

Speed	3000 rpm.
Cylinder coolant temperature	250 F. (glycol coolant)
Head temperature	180 F.
Exhaust back pressure	7 in. of mercury
Load	Wide open throttle
Air-fuel ratio	12.5:1
Spark advance	5 deg. B.T.D.C.
Air-fuel mixture temperature	330 F.
Air to carburetor temperature	270 F.
Intake valve	Pinned
Intake valve seat width	$\frac{1}{8}$ in.

Lubricant—Inhibited paraffinic S.A.E. 30

Of prime interest at this point were the peculiar soft face deposit formed by thermally cracked type 1 fuel and the phenomenon of inducing valve burning by changing fuel types. This problem was of interest because field reports had been received of intake valve burning occurring in a certain few vehicles of a large fleet. This fleet was using a fuel which contained a large percentage of the thermally cracked type 1 fuel. Further reports indicated that the drivers operating the vehicles which were in trouble usually purchased gasoline foreign to the brand used at their home garage at a particular service station midway on their route. It was suspected that in these vehicles a soft valve deposit may have been laid down by the thermally cracked type 1 fuel component which was then baked to a hard brittle deposit by the foreign fuel; this was presumably followed by the valve burning.

To check this effect, which had been indicated in earlier work, an intake valve deposit was first formed on a valve by using thermally cracked type 1 fuel under the severe test conditions shown in the tabulation.

Fig. 4.—Laboratory Valve Deposit Obtained with Thermally Cracked Type 1 Fuel.

A photograph of the valve, after 47 hr. operation, is shown in Fig. 4. Note the heavy fillet deposit. The face deposit was typically soft with no blow-by area in evidence. Blow-by was induced across this face as shown in Fig. 5 by operating for a period of 127 hr. on the straight-run fuel. The blow-by is indicated by the light gray portion on the face. The fillet deposit adjacent to this area is also burned off. This area was then healed by operating for a period of 22 hr. with the thermally cracked type 1 fuel. The healed face is shown in Fig. 6. Following this, straight-run distillate was again fed to the engine and after 60 hr. of operation, blow-by reoccurred as shown in Fig. 7. The blow-by area is to the left of the center of the valve.

These tests demonstrate that with certain fuel types no valve burning will occur under these conditions, even though a heavy valve deposit may be obtained. When a different fuel is used, the character of the previously formed valve deposit is changed and valve burning occurs. This may explain why only certain vehicles out of a large fleet are troubled by intake valve burning.

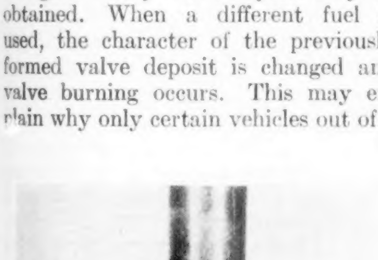

Fig. 5.—Laboratory Valve Deposit from Thermally Cracked Type 1 Fuel Burned with Straight-Run Fuel.

The valve burning characteristics of two other cracked fuels were also evaluated. It was found that with a catalytically cracked type 1 fuel, a brittle face deposit was obtained which guttered and burned the valve in 47 hr. (Fig. 8). The blow-by area is definite and is surrounded by lead salts. The unburned face deposit was quite brittle and spalled when scratched with a probe. The fillet deposit was extremely heavy and bulbous.

A thermally cracked type 2 fuel was also tested, and valve burning was observed in 65 hr. This valve closely resembled the valve burned with the catalytically cracked fuel. The face deposit was quite brittle and was accompanied by a heavy bulbous fillet deposit.

The valve burning observed with these two fuels is in marked contrast to that obtained with thermally cracked type 1 fuel, which did not burn valves by itself.

Fig 6.—Previously Burned Laboratory Valve Healed by Thermally Cracked Type 1 Fuel Deposit.

The mechanism of valve burning seems to involve the formation of a heavy deposit on the valve fillet which gradually builds up on the valve face, forming a uniform deposit over the entire seating area. It appears that at some point on the valve face, the deposit must become brittle and then spall. When this occurs, the passage of the hot combustion chamber gases causes local overheating of the valve, and this results in incipient burning, guttering, and finally in complete failure.

Effect of Air-Fuel Mixture Temperature:

From earlier work it was found that the amount of deposit obtained on the intake valve fillet seemed to vary with the air-fuel mixture temperature. An extended series of tests was made with a thermally cracked type 2 distillate to evaluate systematically the importance of this effect. Each test was standardized at 20 hr. and no attempt made to burn the valves. The assumption made was that the time required to burn the valve would depend upon the amount of brittle fillet deposit.

Fig. 7.—Laboratory Valve Reburned with Straight-Run Fuel.

Two curves illustrating the effect of air-fuel mixture temperature are given in Fig. 9. These show the amount of deposit, based on a visual rating system, obtained with various air-fuel mixture temperatures. Low numbers indicate little deposit. These two curves were obtained from the two cylinders of one engine in the same series of tests and illustrate quite well the extreme difficulty in duplicating this type of experimental data, even in the same engine under as nearly identical operating conditions as possible.

The data from several sequences of such runs show that the amount of intake valve deposit obtained follows the same general pattern, giving the maximum amount of deposit at about 150 to 200 F. air-fuel mixture temperature. Duplicate series of tests do not agree accurately with respect to amount of deposit and temperature for maximum

Fig. 8.—Laboratory Valve Burned with Catalytically Cracked Fuel.

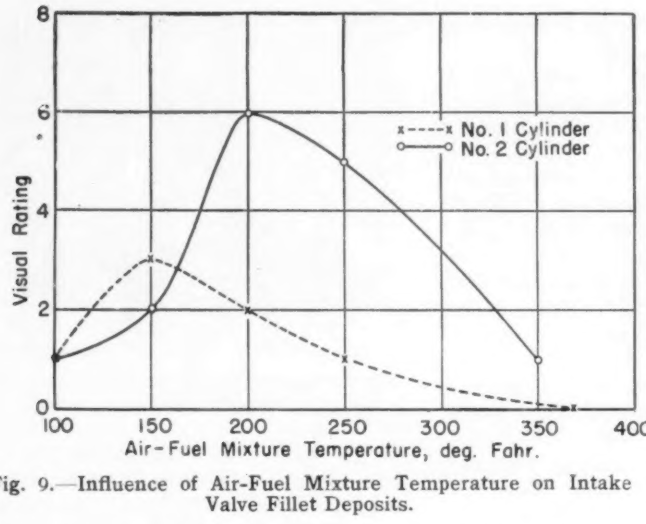

Fig. 9.—Influence of Air-Fuel Mixture Temperature on Intake Valve Fillet Deposits.

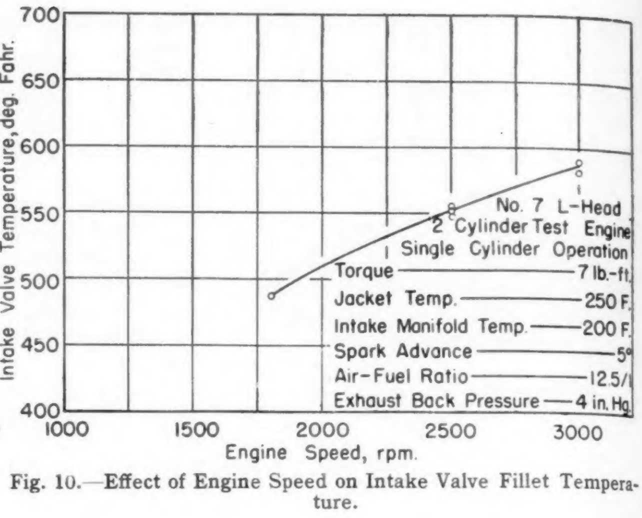

Fig. 10.—Effect of Engine Speed on Intake Valve Fillet Temperature.

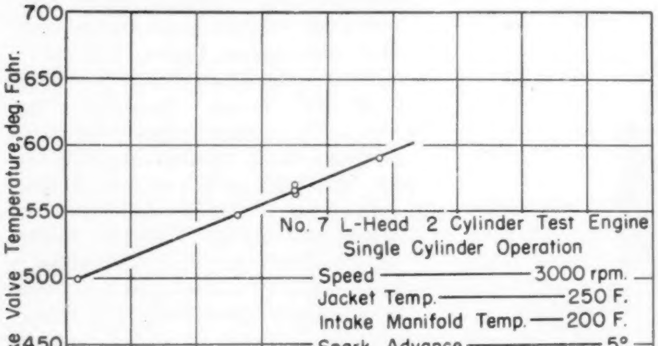

Fig. 11.—Effect of Torque on Intake Valve Fillet Temperature.

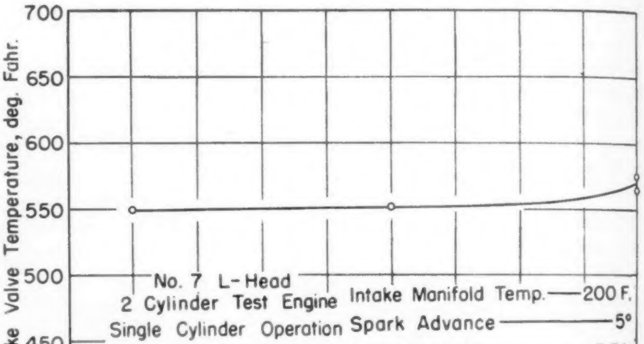

Fig. 12.—Effect of Cylinder Coolant Temperature on Intake Valve Fillet Temperature.

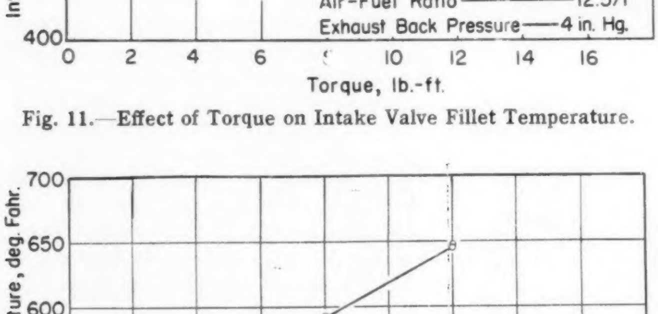

Fig. 13.—Effect of Air-Fuel Mixture Temperature on Intake Valve Fillet Temperature.

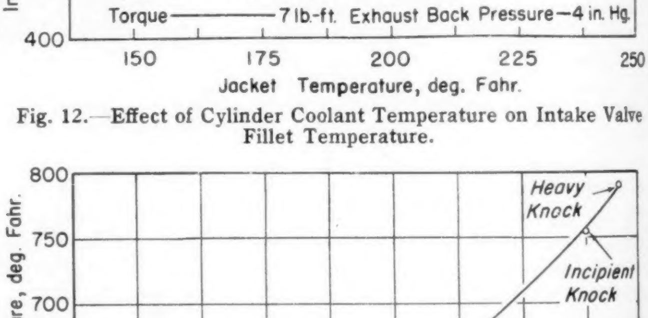

Fig. 14.—Effect of Ignition Timing on Intake Valve Fillet Temperature.

deposition. This may be due to variation in the intake valve temperature caused by slight changes in unknown engine variables. In each series of tests, however, a definite optimum temperature was found above or below which the amount of intake valve fillet deposit decreased rather sharply.

Effect of Engine Operating Variables:

The discovery that there was a particular mixture temperature for maximum valve deposition raised the question as to why the deposits decreased at the higher temperatures. Certainly oxidation of the gasoline in the manifold should be greater as the temperature increases, but if this were the controlling factor, the deposits would not fall off at high temperatures. This reasoning led to the belief that the intake valve surface must become sufficiently hot at the higher mixture temperatures to prevent deposits from adhering. It was therefore decided to conduct a series of tests

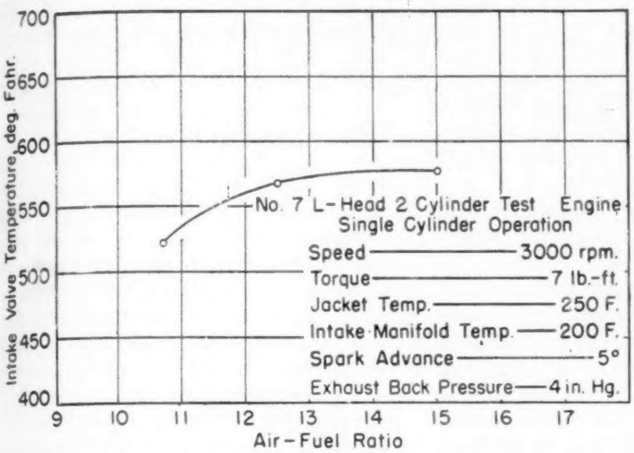

Fig. 15.—**Effect of Air-Fuel Ratio on Intake Valve Fillet Temperature.**

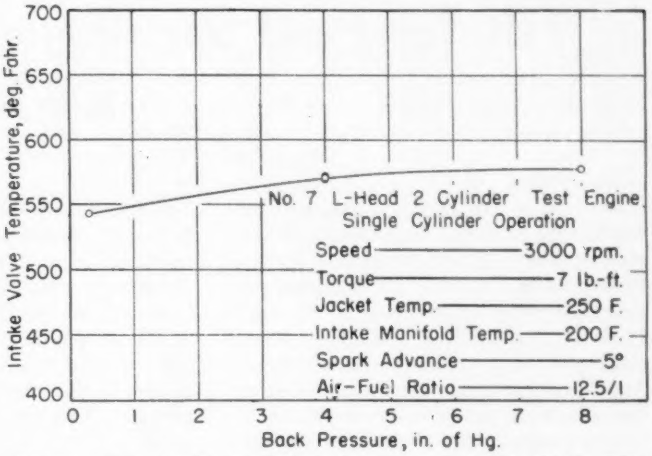

Fig. 16.—**Effect of Exhaust Back Pressure on Intake Valve Fillet Temperature.**

to determine the effect of engine operating variables on valve temperature in order to permit independent variation of the mixture temperature and the valve temperature. If this could be done, it was believed that the separate effects of mixture temperature and valve temperature could be evaluated.

A thermocouple was developed to indicate the relative surface temperature of the valve fillet and a number of experiments made in which engine variables were changed, one at a time, through a reasonable range and the effect on valve temperature observed. Care was taken to allow the engine to reach equilibrium before each reading was recorded.

It can be seen in Fig. 10 that the intake valve temperature varies directly with speed. This temperature also varied directly with engine torque as shown in Fig. 11. The straight-line relationship of these two curves is rather striking. The effect of cylinder coolant temperature is shown in Fig. 12 to be negligible; this is rather surprising and possibly a peculiarity of this particular engine design. The air-fuel mixture temperature (Fig. 13) shows a more or less linear effect on the intake valve temperature. Ignition timing, shown in Fig. 14, effected a considerable increase in valve temperature. As the ignition was advanced from 2 deg. to 32 deg., the valve temperature increased over 200 F. It is interesting to observe that the valve temperature did not change abnormally at the most advanced ignition timing, at which point the engine was detonating rather badly.

Air-fuel ratio, shown in Fig. 15, effected an initial increase of the intake valve temperature to about 12.5:1; above this ratio, little change in temperature was observed. The effect of exhaust back pressure (Fig. 16) was to produce only a slight increase in temperature of the valve.

This last work has only recently been completed and data regarding the relative effect of intake valve temperature and air-fuel mixture temperature on intake valve deposits have not been obtained.

General Conclusions:

From the data, some general conclusions have been drawn with respect to the effect of gasoline type and engine operating conditions on intake valve burning.

1. A set of conditions was found for this laboratory engine which gave significant valve deposits and evidence of valve burning with various gasolines.

2. A curious phenomenon of incipient valve burning and healing was observed. Thermally cracked type 1 gasoline gave a fairly heavy, quite plastic face and fillet deposit, but no evidence of burning. Blow-by could be induced through this deposit by operating with a straight-run fuel. It was further demonstrated that this valve could be healed by operating again with soft deposit-forming thermally cracked type 1 fuel. Blow-by was reinduced with the straight-run fuel.

3. Thermally cracked type and catalytically cracked type 1 fuels gave heavy face and fillet deposits and readily burned valves. The face deposit of the catalytically cracked fuel appeared to be the most brittle.

4. Investigation of the effect of air-fuel mixture temperature on amount of fillet deposits in this engine indicated maximum deposition on the valve fillet to occur, under conditions of the test, at approximately 150 to 200 F. This temperature was critical, the deposition decreasing rather sharply when operating either above or below the optimum.

Present Status of the Work:

The investigation is now being directed toward rechecking certain of the observed effects and to obtaining data on valve deposits as affected by induction system and intake valve temperatures.

As previously stated, this paper constitutes only a progress report setting forth data and conclusions as they have been found to date. This problem will require a considerable amount of additional study before final conclusions can be drawn. It is realized that the results reported here are fragmentary in nature, but it is hoped that they may be of value in suggesting factors which may contribute to the recurring phenomena of intake valve burning.

Acknowledgment:

The authors wish to acknowledge the continuing interest and cooperation of W. A. Gruse of the Mellon Institute and J. E. Taylor and C. J. Livingstone of Gulf Research and Development Co. under whose direction these studies were made. Thanks are also due to R. M. Stewart of Gulf Research and Development Co. for his assistance in the collection of the data.

Felt Tests and Specifications and Their Interpretation[1]

By R. R. Stevens[2]

FELT is a misapplied word. Its use runs the gamut of the roofing, flooring, and mattress industries, despite the fact that the product covered has little relation to felt as used in either A.S.T.M., S.A.E., Felt Association, or Government specifications. Anything that might serve to clarify the line of demarcation between felt and feltlike products should help the average consumer to purchase and use the felt best suited to his purpose.

We all deal with specifications for felt, most of which include various tests and methods for determining test figures. In none of these specifications is there any explanation of the reason why such such tests and test requirements have been set up or what purpose they serve. Many consumers may also wonder what is the value of these tests and what they have to do with quality.

As we all know, there are several kinds of laboratory tests. One type is used so that a purchaser is sure that he gets the same item from various suppliers; another type is a test having something to do with the ultimate or end use of the felt or the felt part. The original quality requirements for felt were set up at least 30 years ago and were simply an adaptation of test controls that were used for textiles in general. They have since been expanded.

Breaking Strength:

Yarns and cloth at that time were tested for breaking strength, and this requirement was tacked onto felt, despite the fact that felt is seldom used where it is subject to a stretching action. As the years went by, the inadequacy of a breaking strength test was recognized in the felt trade, and a further strength requirement was added, namely, splitting resistance.

Splitting Resistance:

Splitting resistance is the amount of resistance offered to the tearing apart of the felt when it is split through its middle section, in other words, slicing into the center of a piece of felt subsequently measuring the number of pounds of pull required to finish pulling it apart.

This test really means something as to the quality of felt, especially felt pads and back checks, because it measures not only the staple length of the wool used to make the felt, but also of the actual felting which is put into the goods. Coincidentally a good grade of wool, and therefore a more expensive wool, has to be used to provide the felting property needed to raise the splitting resistance.

Ash Test:

At the time original felt testing was set up, there was a textile practice on silk fabrics of tin weighing. It was and still is the practice to use China clay, talc, and chalk for the weighting of cotton goods. All of these compounds show up as a residue when the textile fibers present in cloth or felt are burned away or ashed. The ash test was inserted to prevent adulteration and false weighting, and to insure that the consumer got wool or cotton fiber where he desired it.

Matter Soluble in Carbon Tetrachloride:

This test replaced an original double requirement which called for separate tests for alcohol and petroleum ether soluble extractions. Carbon tetrachloride soluble extract is residual oil from necessary picking and carding operations in felt manufacture. Such oil is not intentionally added as an adulterant but is employed to insure against fiber breakage during manufacture, thus providing the consumer with the best value from a given combination of fibers. Carbon tetrachloride soluble matter also includes residual natural wool grease, left from the scouring of the wool. Such wool grease is in no way harmful to machine parts, as in its refined form it is used in face creams and the like under the name of Lanolin.

The basic reason for setting a maximum in the amount of carbon tetrachloride soluble matter is simply to prevent the manufacturer from weighting his product by adding or leaving in it an excessive amount of oil or grease. Many of our consumer complaints that there might be 0.5 per cent excess of such soluble over the specified amount would seem to indicate that the oil might affect the wearing quality, or some other property of the felt, whereas such is not the case. Often, the felt user who complains about excessive oil content will wet out the cut felt part in oil for some mechanical or industrial purpose.

Of course, in the case of felts for water wicking, clothing purposes, and uses where staining may result in contact with white materials, the oil and grease content figures, as represented by the carbon tetrachloride soluble matter, can be important and have a definite bearing on the usefulness of the felt, hence the need for a maximum limit.

Matter Soluble in Water:

The weight of materials that can be extracted by the laboratory treatment of felt with successive washings with boiling water represents the so-called "water-soluble" material. Such material may include residual soap, sizing or stiffening, such as starch and glue, some natural perspiration extract, or wool "suint" from the sheep's wool used, and residual dust and dirt. Here again the exceeding of allowed amounts by 0.5 to 1 per cent should not cause alarm to a customer, because if a felt manufacturer were intentionally adding sufficient sizing or glue to weight his product, the figures would have to run up to or exceed allowed amounts by 3 to 5 per cent, to make it worth while to bother with the weighting operation.

Wool Content:

This term needs little explanation except to say that we should discourage consumers from using wool labeling figures as a control for wool content, or as a specification for purchasing felt. Wool content by prescribed felt testing methods is entirely different from arbitrary figures giving the actual percentage of used, reprocessed, and new wool that any particular manufacturer might employ in making a given felt. Many combinations of various amounts of these types of wool can be used to manufacture felt. Manufacturers are required by law to wool label felts. Such wool labeling is used to prevent misrepresentation of fiber content in the end retail selling, rather than to provide a formula for compounding wool fiber products in making felt.

Tests for End Use:

Methods of test for various end uses, rather than quality control in general, are touched on but briefly for the reason

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[1] This paper was presented at the meeting of Subcommittee A-10 on Felt of A.S.T.M. Committee D-13 on Textile Materials, Detroit, Mich., October 28, 1949.

[2] Chief, Research and Development Department, The Felters Co., Millbury, Mass.

that all such tests vary with the consumer and his requirements.

For example, tests on the Mullen type machine, as shown in A.S.T.M. Methods for Testing Felts (D 461–49),[3] can be applied to the thinner, firmer felts. Many of the thicker felts are not suitable for reproducible burst tests. In all such cases the tare diaphragm pressure is important. The primary field for use of burst tests might well be that of filtering felts.

Other tests which are similarly limited in their application to specific uses of felt include the tests for moisture resistance, mildew resistance, oil absorption, wicking, shrinkage, wash fastness, perspiration and light fastness, crocking, and permeability, or resistance to the passage of air. Many specific tests having to do with end use never will be of sufficient general interest to warrant committee work and are better developed by the individual consumer.

Tests for Woven Goods:

It might be interesting to see how several tests that are used on other fabrics work on felt, and why we have to have special felt testing methods.

In the A.S.T.M. General Method of Testing Woven Textile Fabrics (D 39–49),[4] the trapezoid tear test on fabrics follows down either the warp or the filling, as the case may be. Felt has no yarn structure. Hence when this test is applied to a sample of felt we get a tearing effect to one side, at right angles to the tearing forces involved. This reveals nothing as to the quality of the felt.

For the same reason the tongue tear test does not apply to felt.

Special Felt Tests Necessary:

Due to the wide range of thicknesses in which felt is manufactured, it is necessary to have different considerations when testing the thinner fabrics such as are used for clothing and upholstery. Thus, in some mechanical uses, felt may be subject to a shearing force or forces in which the cross-section becomes a dimension fully as important as to strength and stability as the lengthwise or crosswise dimensional breaking strength.

A test for resistance to shearing might be considered in which the two face surfaces of a sample are adhered to jaws, or adapted jaws, and subjected to a tension pull producing a shearing force in the plane of the felt. Such a test is suitable only when the adhesion to the jaws is greater than the shear resistance of the felt, the basis for this type of test is given in A.S.T.M. Tentative Methods of Testing Rubber Adhesives—Method B. Adhesion Strength in Shear (D 816–46T).[5] Table I shows the relative strength of a number of felts as determined by random tests made to explore this method.

TABLE I.—SHEAR TESTS ON MECHANICAL ROLL FELT.

S.A.E.	Thickness, in.	Width of Text Strip, in.	Face Area Between Jaws, sq. in.	Test Results of Face Area, psi.
No. F-3	½	2	2	110
No. F-7	½	2	2	45
No. F-11	½	2	2	30
No. F-15	½	2	2	15
No. F-26	½	2	2	1¼

Another similar type of test, bringing into play shearing and other forces employs a cut-back specimen in which one half of the cross-section is cut away on opposite sides at each end, leaving a center portion of specified area in full thickness. Tension is then applied in the plane of the cut sections.

Such shear tests are unique for a textile material, as felt is one of the few fabrics that has no yarn structure, but does possess intrinsic internal strength, or cohesion, and is manufactured in thicknesses up to one inch or more.

Use of Fluorescent Dyes:

Looking forward in the field of felt testing, a few observations on the possibility of using fluorescent, or ultraviolet light activated materials, may be of interest. White wool may be dyed or treated with such materials, which are invisible in ordinary light, and added to untreated wools in desirable proportions, previous to felt manufacture. Such blended felts may then be examined under ultraviolet light, at various stages of manufacture to trace travel of fiber, to locate experimental lots, to identify face and back constructions, and to measure the tendency of various fiber felt constructions to come to the surface of the felt.

The advantage in using such a means of testing and identification is the absence of any discoloration of white felt, its permanence and the lessening of bias in judging or processing of sample runs. The use of fugitive stains in marking sample runs is improved upon because identification of white materials can be carried through to the finished stage, whereas colored stains are removed in some intermediate stage of processing.

Such identifying techniques are relatively inexpensive. Compounds are applied from water solutions, rather than solvents. Identifying ultraviolet bulbs cost only a few dollars. There are possibilities of applying such compounds during carbonizing or as an after treatment during wool scouring.

Samples manufactured to take advantage of this treatment show that in a sandwich-like construction wool travels from one plane or laminate into another, although in reference to this particular test the penetration was by no means as extensive as would be expected from general statements to be found in the literature, or from splitting tests run before and after felting.

By the fluorescent treatment of a given component of wool in a blend, the efficiency of blending and also of carding can be evaluated. Such study might be carried further for research in evaluation of the felting of batt formations made by air laying in which there might be no laminated carded webs. Research study of the cause of splittiness in cross-section of thick felts is also possible with this technique. Such fluorescent whitening materials have good fastness to acid and alkali and withstand the usual chemical processing encountered in the manufacture of felt.

This technique is only one of many of the fluorescent selective invisible staining tools which are available for research and testing. It is through such organizations as A.S.T.M. that their possibilities can be brought to our attention and exploited.

[3] 1949 Book of A.S.T.M. Standards, Part 5, p. 426.

[4] *Ibid.*, p. 107.

[5] 1949 Book of A.S.T.M. Standards, Part 6.

Discussions of a Century Ago Concerning the Nature of Fatigue, and Review of Some of the Subsequent Researches Concerning the Mechanism of Fatigue[1]

By R. E. Peterson[2]

SYNOPSIS

This introductory paper consists of two parts:

A description of a meeting of the Institution of Mechanical Engineers at Birmingham, England, in 1849, where the nature of fatigue of metals is under discussion. Some comments are also made concerning the general state of knowledge of mechanics of materials at that time.

A review of some of the subsequent researches concerning the mechanics of fatigue. This includes a discussion of early work concerning the nature of fatigue, metallographic studies, work with single crystals and aggregates of a few crystals, studies with X-ray methods, application of electron microscope, research at elevated temperatures and with nonmetals into conditions governing inter-crystalline and trans-crystalline failure.

Discussions of Fatigue in 1849

One hundred years ago, October 24, 1849, to be exact, we find fatigue of metals being discussed in a meeting at Birmingham, England, of the Institution of Mechanical Engineers, which, incidentally, had been in existence but two years at that time[3] (**1**).[4]

The distinguished Robert Stephenson, second President[5] of the Institution, occupies the chair; a paper "On Railway Axles" (**2**) is being read by Mr. James E. McConnell, Locomotive Superintendent of the London and North Western Railway:

"... our experience would seem to prove that, even with the greatest care in manufacturing, these axles are subject to a rapid deterioration, owing to the vibration and jar which operates with increased severity, on account of their peculiar form. So certain and regular is the fracture at the corner of the crank from this cause, that we can almost predict in some classes of engines the number of miles that can be run before signs of fracture are visible.

"The question of deterioration of axles arising from various causes, which I have enumerated, is a very important one to all railway companies; that some change in the nature of the iron does take place is a well-established fact, and the investigation of this is most deserving of careful attention.

"I believe it will be found that the change from the fibrous to the crystalline character is dependent upon a variety of circumstances. I have collected a few specimens of fractured axles from different points, which clearly establish the view I have stated. It is impossible to embrace in the present paper an exposition of all the facts on this branch of the subject; but so valuable is a clear understanding of the nature of the deterioration of axles, that I am now registering each axle as it goes from the workshops, and will endeavor to have such returns of their performances and appearances at different periods as will enable me to judge respecting their treatment. When it is considered that on the railways of Great Britain there are about 200,000 axles employed, the advantage of having the best proportions, the best qualities, and the best treatment for such an important and vital element of the rolling stock must be universally acknowledged."

Mr. McConnell tells of some experiments he has made:

"In the second experiment ... an axle ... on being bent alternately backwards and forwards (the power being always applied on the same wheel at opposite points) was broken at the twelfth time of bending...."

He also offers advice which if heeded could have prevented many a failure since his time:

"... all my experience has proved the desirableness of maintaining ... (journals of axles) as free as possible from sharp abrupt corners, and sudden alterations in diameter or sectional strength."

The discussion is lively and centers largely about whether or not the structure of a material changes when subjected to vibration. There is considerable difference of opinion among the discussers.

The Chairman, Robert Stephenson, comments:

"Mr. McConnell has expressed a strong opinion, that a change takes place from a fibrous structure in iron to a crystalline one during the time of its being in use. It will be satisfactory if an instance can be pointed out where this change has occurred. I have not been able to satisfy myself from many experiments that any such molecular change takes place.[6] ..."

Mr. Archibald Slate, Birmingham Patent Tube Works,[7] is interested in the performance of pump rods, and describes what may be considered a fatigue testing machine. (Unfortunately he did not break any test specimens since his tests were evidently at a stress level far under the endurance limit.)

"A short time ago ... I made a machine in which I put an inch square bar subjected to a constant strain of 5 tons and an additional varying strain of $2\frac{1}{2}$ tons, alternately raised and lowered by an eccentric 80 or 90 times a minute. This motion was continued for so long a time that I consider it equal to the effect of 90 years' railway working, but no change whatever was perceptible. I am therefore one of those who does not believe in a change from a fibrous to a crystalline structure in iron. ..."

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[1] Presented as the introductory paper at the Session on Fatigue of Metals held on October 10, 1949, at the First Pacific Area National Meeting, San Francisco, Calif.

[2] Chairman of A.S.T.M. Committee E-9 on Fatigue; Manager, Mechanics Dept.; Westinghouse Research Laboratories, East Pittsburgh, Pa.

[3] The original members were 70 in number; one of the requirements of membership was that of being "managing-head of an establishment where engines or machines are made or employed." There was, however, a provision that other eminent mechanical engineers might also be admitted.

[4] The boldface numbers in parentheses refer to the list of references appended to this paper.

[5] George Stephenson, the "Father of Railways," was the first President. Next to George Stephenson, his son Robert ranks easily as the greatest of the pioneers of the railway system. Robert was largely responsible for the design of the famous "Rocket" whose performance at the Rainhill trials in 1829 definitely established the position of the steam locomotive in railway traction. He soon gained a reputation as a railway engineer second only to that of his father, after whose death he rose to the same unrivalled eminence. Robert Stephenson became famous for the boldness and excellence of his bridge building. He was a Member of Parliament for twelve years, was elected F.R.S. in 1849, and was President of the Institution of Civil Engineers in 1856 and 1857 (**1**).

[6] Further discussion of Robert Stephenson occupies two pages of the I.M.E. *Proceedings*, reference (**2**), pp. 22–25. (I.M.E. discussions are recorded in third person.)

[7] Archibald Slate was also first Secretary of the I.M.E.

Mr. John Ramsbottom, Chief Engineer of the London and North Western Railway, believes that a change takes place and comments:

> "A parallel case might be observed with reference to an ash stick which if doubled will break with a fibrous fracture; but if subjected to vibration, however slight, running through it a great number of times, it will break in a different mode."

The Chairman, Robert Stephenson, intervenes for the second of three times, to offer sound advice:

> "I am only desirous to put the members on their guard against being satisfied with less than incontestable evidence as to a molecular change in iron, for the subject is one of serious importance, and the breaking of an axle has on one occasion rendered it questionable whether or not the engineer and superintendent would have a verdict of manslaughter returned against them. The investigation hence requires the greatest caution; and in the present case there is not evidence to show that the axle was fibrous beforehand, but crystalline when it broke. I therefore wish the members of the Institution, connected as you are with the manufacture of iron, to pause before you arrive at the conclusion that iron is a substance liable to crystalline or to a molecular change from vibration. . . ."

This is followed by Mr. McConnell's furnishing what he believes to be "nearly incontestable evidence of the truth of my position." After much more discussion, the meeting ends, leaving the question far from settled. So much, then, for our looking in at this meeting 100 years ago.

The discussion along the foregoing lines continued throughout 1850, in the meetings of January 23, April 24, and October 23 (the Institution held four meetings annually at that time). It is not worth while to go into detail concerning these discussions; only two discussions will be noted, one humorous and the other technically significant.

Mr. P. R. Jackson suggested that a vote of those present be taken as to opinion regarding whether a material remains fibrous or becomes crystalline under vibration. The chairman, however, was equal to the occasion and replied that such a vote would be contrary to the practice of the Institution.

Mr. P. R. Hodge remarked (3) that to arrive at any true results as to the structure of iron it would be necessary to call in the aid of the microscope to examine the fibrous and crystalline structure.

This excellent suggestion, which seems so obvious to us now, was pursued by Robert Stephenson who reported (4) that he had since the last meeting examined "a piece of iron called crystalline, and a piece of iron called fibrous" under a powerful microscope and that it would probably surprise the members to know that no real difference cou'd be perceived.

The direct effects of repeated straining were not to be observed microscopically for another half century. The statement of Robert Stephenson did not end the discussion by any means. Mr. McConnell stated that an alteration took place in the quality or condition of the iron as was manifest from a great abundance of evidence; and he thought that it would be a decided improvement if they would adopt some other word which could express the quality or condition of iron in its (brittle) state; it was clear that a change did take place, making that which was originally tough quite brittle.

One might ask at this stage why the writer has devoted so much space to the early Institution of Mechanical Engineers meetings, since no conclusions or direct results seemed to have been attained. These are not even the first discussions of the subject.[8] The centennial aspect is, of course, of interest, but more important is the fact that these meetings were characterized by particularly spirited discussion which was carefully documented. It should be noted that, in the fatigue of metals field, the concepts which we now so readily accept as self evident were not easily gained. The elementary facts of fatigue of metals could not be forthcoming until systematic tests were made. The tests of James and Galton had been carried out for the "Iron Commission," but the significance of these tests was not fully appreciated at the time.[9] The well-known investigations of Fairbairn (12) and Wöhler (13) were to come later.

It is of interest to note that the steam engine and its application to pumps and locomotives introduced dynamic repetitive loading of a magnitude not experienced previously in machinery and structures, with the result that fatigue failures occurred in service; this field experience led to the early work indicated above.

The approach was therefore an engineering one, intended to answer practical questions. The first main facts might have been discovered by means of abstract investigations of the effects of cyclic loading on materials conducted entirely along scientific lines; such a sequence was evidently not responsible for opening the field of fatigue of metals. In view of this circumstance, considerable importance should be attached to meetings where experiences are reviewed and discussions take place aimed at interpreting and understanding service behavior. This comment is meant to apply to our meeting today as well as the one a century ago.

It is a pleasure to note that airplane designers are participating in this present session, and it is hoped that the discussion will be as wide open as was the case a century ago; and that we will also admit what we do not know, with the idea of starting investigations to understand what we cannot now explain.

Review of Some of the Subsequent Researches on the Mechanism of Fatigue

The question of "crystallization," under discussion a century ago, was not completely clarified for a long time.[10] Older ideas were not easily discarded: it had been thought that *magnetism*[11]

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[8] See, for example, references (**5**, **6**, **7**, **8**, **9**, **10**).

James Nasmyth, famed inventor of the steam hammer, in a lecture in 1842 (**6**) stated that "In locomotive engines the axle was the chief point of danger; and it was therefore important, both as a scientific and practical question, to determine the nature and habitude of iron when placed under the circumstances of a locomotive axle. Experiment was the only way to discover this, and he would have wished to place iron under exactly similar circumstances; but the short time intervening since the subject had come before the Section had rendered it impossible to do so. One opinion was, that the alternate strains in opposite directions, which the axles were exposed to, rendered the iron brittle, from the sliding of the particles over each other. To illustrate this, Mr. Nasmyth took a piece of iron wire and bent it back and forward; it broke in six bends."

The subject was not unknown in America at these early times. Prof. Mapes (**10**) in 1844 comments "Notwithstanding the many fashionable hypotheses in relation to the wearing out or ultimate noncohesion of the particles of iron in railroad tracks, by weight of load and linear impingement, still it was clearly shown that by practical results, stated at these conversations, when a rail was of sufficient width and thickness, the impingement of the wheels did not deteriorate the quality."

[9] In 1847 a commission was appointed "to inquire into the application of iron to railway structures." In this connection Captains James and Galton made a variety of tests including some repeated stress tests. The Commission report was published as a government document in 1849 (**10a**). The results were not published by James and Galton before a technical society. The main findings were, however, mentioned by Fairbairn in 1850 (**11**) and discussed in more detail in 1864 (**12**).

[10] Mr. R. L. Templin points out that considerable misunderstanding still exists regarding "crystallization." He felt that a notable educational contribution was made by the National Bureau of Standards *Letter Circular LC 204* "Metals Do Not Crystallize Under Vibration," July 14, 1926 (Replaced by *LC 486*, January 6, 1937).

[11] "The rapid rotation of the axle produces a powerful magnetic action, while the friction causes much heat; and these effects, added to the constant percussion which is produced by the peculiar motion of railway wheels, cause crystallization to be produced with extreme rapidity; the effect being probably further increased in the axles of locomotive engines by the magnetizing power of the electricity generated by the effluent steam" from paper by Charles Hood (F.R.A.S.) before Inst. of Civil Eng. (1842) (**7**).

M. Francois and Col. Aubert in their report to the French government concerning axle failures attribute the crystalline appearance of fracture to "magnetic and electric changes in the molecular structure of the iron caused by friction in the bearings and great velocities" (**8**).

was a factor, that steady load would cause deterioration of a member with *time* (14), that *loading velocity* (15) would explain the mysterious service failures, that repeated loading induced *permanent set* (16), etc.

While we have mentioned, in the title of this paper and elsewhere, early discussions of fatigue, this name was not used at first, but instead the phenomenon was more apt to be called "crystallization due to vibration" or to some other cause, such as mentioned above. The term "fatigue" was first introduced into the literature in 1854 by Braithwaite (17) who said that the term had been suggested by Mr. Field.[12] As might be expected, this new term brought forth discussion as to its appropriateness (such discussions are still forthcoming). Braithwaite replied that he merely adopted Mr. Field's term because it was the most expressive he could find and because the action was progressive (a reasonable answer, then and now).

The concept of an endurance limit was established by the tests of James and Galton, Fairbairn and Wöhler; this was a necessary concept since the question is not whether vibration has an effect on metal, but what vibration amplitude is required for an effect to manifest itself. (Archibald Slate, for example, ran all of his tests under the endurance limit.)

The use of the metallurgical microscope, in studying effects of fatigue, suggested nearly 100 years ago, was of great importance in advancing knowledge of the mechanism of fatigue of metals. A number of excellent papers dealing with research by metallographic methods appeared in the years just before and after the turn of the century.

A milestone along this road is the work of Ewing and Rosenhain (18) in describing "slip bands" and thereby showing what happens as elastic conditions become exceeded locally. By straining the specimen *after* polishing and etching, it became possible to obtain observable effects.

This was followed by the work of Ewing and Humphrey (19) wherein the behavior of a polished and etched specimen subjected to repeated stress was observed under a microscope. The connection between slip and eventual breakdown in fatigue was established by this work. Regions of heavy slip were shown on polishing and etching to have developed cracks corresponding in location to the original slip lines.

Scientific work in a new direction is not without a certain excitement, as one can sense by reading the discussion (20) between Rosenhain of England, Osmond of France, and Heyn of Germany.

Further research with the aid of the microscope was carried out by Gough and Hanson (21) who coupled precise mechanical tests (static and fatigue) with observations under high magnification. It was shown that slip lines occur under the endurance limit and in some cases even below the proportional limit.

Research on the fatigue of single crystals was started by Gough and his co-workers (22) in 1923 and extended over the following ten years (23). This work covered such materials as aluminum, iron, zinc, silver, antimony, and bismuth; in most cases single crystals were tested, but in a few cases groups of a few crystals were contained in a test section. These investigations were characterized by X-ray determination of the lattice orientation with respect to the axis of the test specimen and an analysis of the stresses acting in the principal directions on the crystallographic planes. The specimens were subjected to repeated torsion and the resulting slip lines and fatigue cracks were observed with a microscope. It was found that slip occurred in accordance with the maximum resolved shear stress.[13] In traversing around a single crystal specimen subjected to torsion the directions of maximum resolved shear stress change, and it is interesting to note how sharply the slip lines change in direction accordingly.

Slip behavior as just described is produced by static loading or by repeated loading. With repeated loading there is a tendency to slip back and forth on a particular slip plane; this usually brings forth a "contest" between two tendencies: a tendency to work harden in the region of the slipping surfaces and a tendency for the slipping surfaces to break down into a separation or crack. Sometimes the first predominates, as in the case of understressing where there is considerable slip but no failure, and sometimes the latter predominates in which case the usual fatigue failure results. The conditions which determine the outcome of the "contest" are not well understood.

Orowan (26) has suggested a model wherein a plastic element in an elastic surrounding undergoes strain hardening in decreasing amounts with numbers of cycles. As the plastic element strain hardens, the stress acting on the element increases. If the stress reaches the failure value, a crack occurs and fatigue failure follows due to the spreading of the crack. If the plastic element does not attain the critical failure value before strain hardening ceases, fatigue failure will not occur. Although fatigue failure is more complex than is represented by Orowan's model yet the basic mechanism which Orowan proposes must certainly form a part of any adequate description of fatigue failure.

As we have noted, certain slip lines eventually become separations or cracks. One or more of these minute sources starts to spread and this develops into a gross crack which, in general, meanders through the grains in a zig-zag fashion in an average direction normal to the direction of tensile stresses. It should be remembered, however, that although the fractured surface generally follows a normal stress field, the microscopic source of failure is due to shear.

In design involving combined stresses, shear theories are used, either the maximum shear theory or the shear-energy theory. With regard to the latter, there appear to be two schools of thought: one group sees real significance in energy[14] *per se* as a criterion of failure while the other group (28, 29, 30) points out that if one considers random orientation one obtains, analytically, approximately the same ratio, $1/\sqrt{3}$, of torsion yield to tension yield.

While a complete theory has as yet not been determined, it can at least be said that, for ductile materials, shear is the basic mechanism determining the start of failure. Since plasticity is also a shear phenomenon, the large amount of work in the field of plasticity will undoubtedly produce results which will be useful in the fatigue field. The theory of dislocations (31) is of interest in this connection.

X-ray diffraction methods have been used to determine structural changes associated with failure (32, 33, 34, 35). A breakdown of the grains into a mass of crystallites having a limiting size of 10^{-4} to 10^{-5} cm. occurs whether static or repeated loading is used to produce failure. Cycling to failure results in heavy lattice distortion of the crystallites, indicating severe internal stresses in the crystallites. Later tests by Wood and his associates (36) have shown residual stresses in the lattice (not to be confused with gross residual stresses in a test specimen) as a result of yielding. Further work of this kind needs to be done in close correlation with cycling tests in the region of the endurance limit.

The electron microscope has been used to study the slip process in aluminum crystals (37). A "slip line" or "slip band" in aluminum was shown to be a laminar region consisting of a large

[12] Presumably Joshua Field, F.R.S., President of Institution of Civil Engineers, 1849.

[13] See also previous work on single crystals subjected to static stress (24, 25).

[14] See review of recent views on energy theories (27).

number of laminae about 200 Å thick and relatively displaced about 2000 Å. If this technique could be used to determine the effects of cycling, it seems that a better understanding would be obtained of the mechanism of the development of slip into separation or cracking.

It is of interest to examine the conditions of failure in a material where slip and work-hardening do not exist. Tests have been made of glass rods (**36**) in bending under three conditions—(*a*) nonrotating, (*b*) rotating 14 rpm., and (*c*) rotating 10,000 rpm. For various stress levels, the average time to fracture was found to be approximately the same.[15]

It is of course well known that steel at constant stress and high temperature will fracture with time, the time interval depending on the applied stress. This is the so-called "creep-rupture" phenomenon, which has become of major importance in gas turbine design. The same phenomenon occurs in lead at room temperature. Creep-rupture fractures in general are characterized by being inter-crystalline, while the usual fatigue fractures are trans-crystalline. Moore (**39**) cites a case where fatigue tests were made at 1200 F. of 0.20 per cent carbon steel at 300 cycles per minute and at 2500 cycles per minute; when plotted on a *number-of-cycle-to-fracture* basis the curves were separate, but when plotted on a *time-to-fracture* basis one curve represented both sets of data. Moore cites this as a coincidence, but one cannot help but notice the similarity to the results with glass. Moore also states that in fatigue tests of lead at room temperature the *time-to-fracture* seems to decrease as the frequency increases.

With regard to mechanism of failure at elevated temperature, the work of Hanson and Wheeler (**40**) is of interest. They made microscopic examinations of aluminum specimens subjected to prolonged loading at temperatures up to 400 C. They found that at the higher temperatures, the number of slip lines increased to an extent that they became difficult to detect. In other words, for a given deformation, an increased number of steps means smaller displacements; it was suggested that in some cases the slip lines may be invisible under the microscope.

It is quite evident that a fruitful direction for research lies ahead in the exploration of the relationship between the above fields where these overlap or border on each other. It should be pointed out that considerable scatter is apt to occur in rupture testing; from an examination of the work of Gurney and Pearson (**38**) it is quite evident that if they had not approached the problem statistically by using a large number of specimens (72 specimens were used for each curve) the results would have been too scattered to be of any value.

Recent studies on grain boundary effects by Boas and Hargreaves (**41**) have indicated that a mechanism other than slip may be operating near the boundaries during deformation. Further work in this direction may have a bearing on the mode of failure (trans-crystalline or inter-crystalline) discussed above. A recent paper by Radavich (**42**) seems to indicate that the electron microscope may be useful in studying grain boundary phenomena. The grain boundaries of ingot iron varied from 0.08 to over 0.4 micron in thickness. Certain brittle conditions seemed to be associated with the thicker boundaries.

Concluding Remarks

As implied by the title, we have been concerned in this paper with the nature of fatigue. There is of course an engineering side of fatigue of metals concerned with the accumulation of extensive and valuable data for design use. It is beyond the scope of this paper to review the achievements on the engineering side or to mention the important men responsible for the main results. There is even a large research field in fatigue of metals, apart from research on mechanism of failure, dealing with effects of varying loads, understressing, overstressing, size effect, notch effect, application of statistical theory, etc. Again these are outside the scope of the present paper.[16]

In the present paper we have noted how the limited knowledge of the early 1800's with regard to mechanics of materials was entirely inadequate to explain the mysterious failures occurring due to the advent of steam-driven machinery. The metal presumably "crystallized," but it was not generally realized that repetition of loading was involved. We have noted how the concept of an endurance limit was established. We have also seen how the "crystallization theory" of a century ago has been proved unsound by metallographic studies. Further, we have noted outstanding work in more recent times with single crystals and groups of a few crystals. The mechanism of slip in accordance with maximum resolved shear stress has been mentioned. Attention has been called to the common ground of plasticity and fatigue. The use of the X-ray diffraction method has also been noted, as well as possible use of the electron microscope. Conditions of failure in glass and in lead at room temperature and in steel at high temperature have been mentioned.

In conclusion, while we have learned a great deal about the nature of fatigue of metals in the past 100 years, it is apparent that the mechanism of slip, of creep-rupture, and of fatigue cracking afford ample opportunities for research. It is hoped that this brief paper will serve to stimulate further work in this field, and that the review and references given will be helpful to those contemplating work aimed at furthering our knowledge of the mechanisn of failure of materials.

[15] This is an especially striking result when one considers that the volume of material subjected to peak stress is different in the rotating and nonrotating cases and that the time at peak stress of any given point is different in rotating and nonrotating cases. The above two circumstances may offset each other; this could be clarified by special tests planned to eliminate one of the effects.

[16] Reviews of a broader nature have been published in recent years (**39**, **43**).

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DISCUSSION

Mr. S. Timoshenko [1] (*by letter*).—We have to thank Mr. Peterson for his paper on fatigue of metals in which the most important steps of the development in this important field are briefly discussed and the principal bibliography is presented. It seems very desirable to have made from time to time by experts such reviews of various fields of testing materials.

To me the historical part of the paper is especially interesting. Peterson tells us about discussions on fatigue of metals which took place a hundred years ago in the London meeting of the Institution of Mechanical Engineers. England was at that time the leading country in the development of machine industry and in railway construction. There were new problems for engineers to solve, new materials to be investigated, and the question of fatigue of metals was of primary importance for English engineers. That was the time when the famous "Report of the commissioners appointed to inquire into the application of iron to railway structures" was published (1849), and the English Board of Trade tried to formulate some requirements regarding safe stresses in bridge construction.

Similar interest in fatigue of metals we see also in other countries. Recently I have read reports[2] of two French engineers in charge of postale coaches on French highways. On the basis of twelve years of experience they came to the conclusion that the axles must be renovated after every 60,000 kilometers of service, since it is likely that due to stress fluctuation and repeated impact in that service, thin cracks may be developed in the axles in the places of sharp change of cross-section. They say that if proper attention is not given, these cracks gradually develop under service conditions and finally bring fractures of axles. They recommend eliminating sharp changes in cross-sectional dimensions and sharp reentrant corners from which the cracks usually start to develop. In conclusion they give sketches illustrating

[1] Stanford University, Palo Alto, Calif.

[2] A. Morin, "Résistance des Matériaux," Vol. 2, p. 114, Third Edition (1862).

gradual development of fatigue cracks.

Regarding the term "fatigue," which the author ascribes to Mr. Braithwaite (1854), it seems that in France this term was used earlier. I find that J. V. Poncelet in his lectures on applied mechanics[3] (1839), given to workers in Metz, speaks of "fatigue" of metals under the action of repeated reversal of stress.

The concept of "endurance limit" must be ascribed, in my opinion, to A. Wöhler. The investigators, H. James and D. Galton, who worked in fatigue before Wöhler, do not speak of magnitude of stresses in bars subjected to repeated transverse loading and unloading. They arrange the experiments so that the maximum deflection, in their tests, represents the deflection which would be produced by a definite portion of the ultimate load. But since before fracture occurs the bars obtain considerable permanent set, we cannot make a definite conclusion regarding maximum stresses used in those experiments. At the same time the concept of "endurance limit" is closely connected with the notion of the "limiting stress."

A. Wöhler in his work of 1856–1857[4] on fracture of railway axles proceeds in a perfectly logical way: Using certain devices, which he developed himself, he measures the maximum deformations of axles in bending and torsion under service conditions. Using now a dynamometer he establishes by the direct test the forces which must act on axles in service and calculates the corresponding peak stresses. Having this information he plans his experimental work and tries, by application of a large number of cycles of reversal of stresses, to establish for each material the limiting stress which can be safely applied an indefinitely large number of times. Only by having this limiting stress for each particular material can a designer properly select safe dimensions of axles.

When we read Wöhler's work today we can clearly see that this work is developed on a much higher scientific level than all investigations made before him, and it seems there is no mistake if we place Wöhler as the first engineer who brought scientific methods to the investigation of fatigue of materials.

Mr. R. E. Peterson (*author's closure*).—It is rather interesting that the Timoshenko discussion concerns the part of the paper dealing with the early history of fatigue. The author must admit that he had some doubts about this part of the paper, stemming partly from a feeling of treading unfamiliar ground and partly from wondering whether readers would really be interested in early historical material. If we find some pleasure discussing such material, perhaps we will feel better about using some of the Society's valuable space if we recall the adage of Cicero "He who knows only his own generation remains always a child."

Timoshenko states that the concept of "endurance limit" must be ascribed to Wöhler, whereas the author associated this concept with the names of James and Galton, Fairbairn and Wöhler. As the result of tests of iron bars repeatedly deflected by a cam (Fig. 1), James and Galton in the 1849 Commission Report[5] state: "It must therefore be concluded that iron bars will scarcely bear the reiterated application of one third their breaking weight without injury." The cast-iron bars tested as simple beams were 3 in. square and had a span of $13\frac{1}{2}$ ft. The static breaking deflection was about $5\frac{1}{2}$ in. During cyclic testing a permanent set of about $\frac{1}{8}$ in. occurred within the first 150 cycles, although some bars failed at 20,000 to 50,000 cycles. The cam was adjusted every 50 cycles early in the test to take account of the permanent set. It seems that such a testing procedure should not invalidate their conclusions, particularly the general idea of a limiting value.

Unfortunately, the interesting results of James and Galton do not seem to have been presented formally before a techni-

[3] J. V. Poncelet, "Introduction a la Mécanique Industrielle," p. 317, Third Edition. This edition is a reprint of second edition of 1839.

[4] *Zeitschrift für Bauwesen*, Vol. 8, p. 641 (1858).

[5] "Report of the Commissioners appointed to inquire into the application of Iron to Railway Structures," Wm. Clowes and Sons, London, for her Majesty's Stationery Office (1849). A copy is on file in the British Patent Office, London.

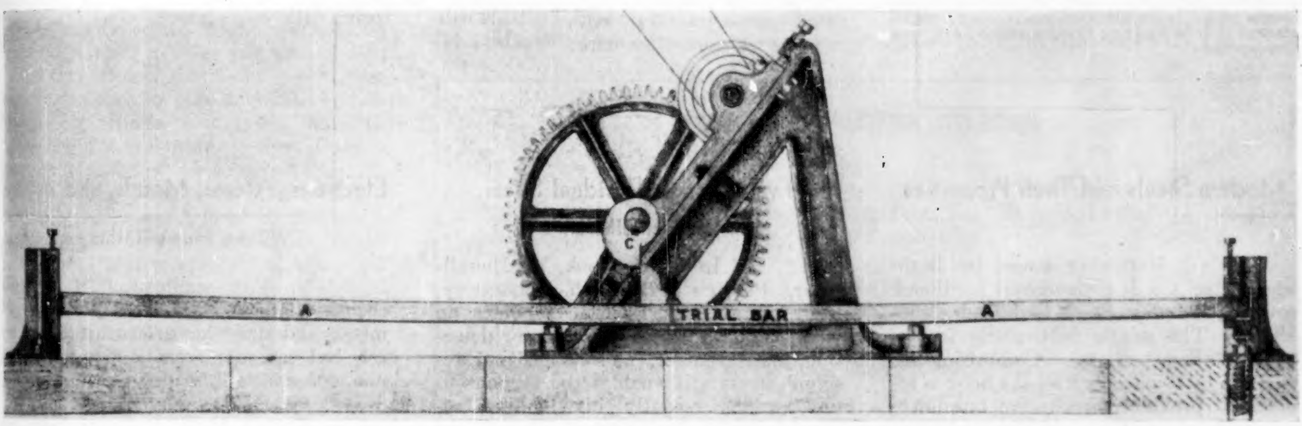

Fig. 1.—Machine of James and Galton.

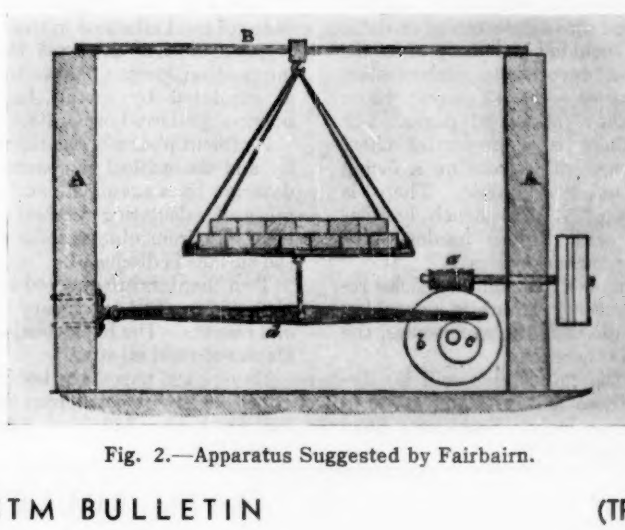

Fig. 2.—Apparatus Suggested by Fairbairn.

cal society. However, Fairbairn,[6] in discussing the Torksey bridge before the Institution of Civil Engineers on March 12, 1850, states (referring to the Commission Report) "it has been shown that to resist the effects of reiterated flexure, iron should scarcely be allowed to suffer a deflection equal to one third of its ultimate deflection."

As mentioned in the present paper, the significance of the James and Galton findings did not seem to be fully appreciated at the time; while the results were discussed before the Institution of Civil Engineers (as mentioned above), there is no recorded discussion of the results in the meetings of the Institution of Mechanical Engineers, which occurred at about the same time and which are discussed in some detail in the present paper. This is perhaps not surprising since the Commission was appointed "to inquire into the application of iron to railway structures"[7] and the men who guided the tests were mainly interested in bridges. However, the findings were quite general and applicable to other problems. But in fairness to the mechanical engineers, it should be realized that it must not have been altogether obvious that there is a connection between a test wherein a piece is bent back and forth and a rotating railway axle subjected to a substantially constant bending moment.

Further mention of the James and Galton findings occurred in later meetings of the Institution of Civil Engineers, and the statement quoted was usually the general one of James and Galton (1849), which expresses a limiting value for iron and makes no reference to bridge design. Since Wöhler published a sketch of his machine in 1858 and published his first results in 1860 it would seem that the idea of a limiting value existed earlier.

This is not meant in any way to detract from the monumental work of Wöhler. The excellence of his testing machine designs and the logical progress of his experiments can only be appreciated by studying his original papers. It is safe to say that Wöhler did not know about the British work, just as the British in reporting Wöhler's work did not know about the James and Galton work. The story of Wöhler's classic work should be told, but this will need to be done elsewhere.

In passing, it is of interest to note that in a letter to the "Iron Commission" dated December 16, 1847, Fairbairn suggested the apparatus shown in Fig. 2. He states that "In the present state of our knowledge the subject of the effects of vibratory action upon metals is but imperfectly understood.... In the suggestions which I have thus thrown out for consideration, I have confined myself almost exclusively to experiments on a small scale which might be done at moderate expense...." The James and Galton machine (Fig. 1) was apparently an outcome of Fairbairn's recommendations.

It seems that our discussion of the present paper has been concerned entirely with the state of knowledge existing a century ago; in this situation perhaps we should agree with the introductory remarks of the author of the History of the Institution of Mechanical Engineers 1847–1947: "To add a technical interest to the story, a number of the discussions of the first half-century have been considered with the object of indicating the opinions and practices of the period. The discussions of the second half-century are too near our own time for any such selection to be justifiable at present and the duty of making it can better be left to some historian fifty years hence."

[6] W. Fairbairn, "On Tubular Girder Bridges," *Proceedings*, Inst. Civil Engrs., Vol. 9, p. 278 (1849–1850). Meeting of March 12, 1850.

[7] The Commission was appointed at the Court of St. James under the sponsorship of Queen Victoria, August 27, 1847. The purpose is defined as follows: "...shall endeavour to ascertain such principles and form such rules as may enable the Engineer or Mechanic, in their respective spheres, to apply the Metal with confidence, and shall illustrate by theory and experiment the action which takes place under varying circumstances in Iron Railway Bridges which have been constructed."

Modern Steels and Their Properties

Recently issued by Bethlehem Steel Co. is a significant handbook covering "Modern Steels and Their Properties." This relates particularly to carbon and alloy steel bars. Comprising 230 pages, 6 by 9-in. page size, the book is intended to provide authoritative, but down-to-earth information on bars and bar material. Following a brief metallurgical introduction, there are a number of short articles on current developments together with numerous up-to-date tables of data. There is also included a glossary of terms.

The section devoted to carbon steel charts, comprises some 40 pages; those relating to alloy, about 60 pages. For each steel there is a properties chart showing average values and on a facing page, data on mass effect. There is information on the end-quench hardenability test, with typical hardenability curves for the various grades.

Some of the short technical articles relate to machinability, grain size, quenching media, magnetic analysis, supersonics, the P-F test, and others.

Copies of the publication will be distributed to those making application to the Publications Dept., Bethlehem Steel Co., Inc., Bethlehem, Pa.

Evaluation of Residual Stress

K. Heindlhofer

In his new book, Mr. Heindlhofer, Physicist, Research Laboratory, United States Steel Corp., provides an advanced treatise on the nature, detection, measurement, and analysis of residual stress It enables the student to use various recently invented instruments, such as electric strain gages, in the effective study of residual stress, and to interpret the results with accuracy.

Following an exposition of the significance of residual stress in the metal industry, the author discusses the limitation imposed on stress analysis by anisotropy as exhibited by metals having a pronounced preferred orientation.

Pertinent phases of the theory of elasticity and the critical representation of the data are then examined, and the impossibility of calculating residual stress within the body from observations restricted to the surface is discussed.

Two chapters are devoted to methods of observation and necessary instruments and circuits. The book concludes with examples of residual stress.

Having 196 pages, the book may be obtained at $4 per copy from the McGraw-Hill Book Co., 330 West 42nd St., New York 18, N. Y.

Electrons, Atoms, Metals, and Alloys

William Hume-Rothery

The application of electron theory to the structure and properties of metals and alloys has aroused much interest, but presents great difficulty to the nonmathematical reader. This book, "Electrons, Atoms, Metals, and Alloys," by Dr. William Hume-Rothery, Lecturer, University of Oxford, England, is intended for the reader to whom the ordinary textbook descriptions are unattractive. The subject matter is divided into four parts dealing with the structure of atoms, metals, alloys, and atomic nuclei. It is presented in the form of a dialogue between an older metallurgist and a young scientist, and brings out clearly the contrast between the old and new viewpoints. Although written primarily for the metallurgical reader, many others will find the book valuable as an elementary introduction to modern atomic theory, while for many students the book may serve as an easy introduction to the more formal treatment of the standard textbooks.

This 377-page book is distributed by Iliffe & Sons, Ltd. Dorset House, Stamford St., London S.E.1, England, at a nominal cost.

Conference on Application of Radioactive Isotopes to Materials Testing

A CONFERENCE will be held during A.S.T.M. Committee Week in Pittsburgh on Wednesday, March 1, at 8:00 p.m., in the William Penn Hotel, at which consideration will be given to the advisability of organizing a committee on the use of radioactive isotopes in testing.

A number of uses are now being made of these isotopes in various testing problems (some of these are set forth in the 1948 Marburg Lecture by Dr. Aebersold), particularly in chemical analysis, and it may well be that these uses will be extended quite rapidly.

At this conference it is intended to review the engineering applications of isotopes and ascertain whether such a committee should be set up in the Society to advise the various technical committees on problems of testing where radioactive isotopes would be used.

Monte Carlo Method (?)

IN A GALAXY of authorities and experts such as constitute the Society membership and BULLETIN readers, one might expect to learn of different systems and techniques that might be used in connection with devices and games used to extract "coin of the realm" from those who are willing to take a chance on the infrequent returns from such hazards. Actually, the following excerpt from a statement will not reveal any technique for "breaking the bank at Monte Carlo." It simply is an example of nomenclature necessary in certain specialized fields. This relates to a symposium of numerical analysis. This is a new branch of applied mathematics. Those interested can get further information by contacting the National Bureau of Standards in Washington.

"The Monte Carlo method can be described quite generally as representation of a physical or mathematical system by a sampling operation satisfying the same probability laws as the system itself. Thus, for example, the numerical integration of partial differential equations of a certain type can be accomplished by building up a large sample of trials of certain stochastic processes whose probability functions asymptotically satisfy the differential equations. In certain physical situations, the physicist may prefer to place primary emphasis on the random processes and the associated sampling operations, regarding them as a new kind of mathematical model."

There you are! You place your money and chips. We're not responsible!

1949 Proceedings of the American Wood-Preservers' Association

The 1949 Proceedings of the American Wood-Preservers' Association is now available. With this edition a new format and larger page size has been adopted representing the first change in form since the first volume was published in 1905. This Proceedings contains fifteen technical papers and thirty-three reports of standing committees. Subjects discussed provide a broad account of the many phases of wood preservation including preservatives, treatment methods, and service records. Applications of wood preserving techniques in such fields as railroads, communications, and mining are dealt with. Important supplementary matter includes "Wood Preservation Statistics" for the year 1948, collected and compiled by Henry B. Steer of the U. S. Forest Service. Two hundred and fifty wood preserving plants in the United States are also listed.

The A.W.P.A. Proceedings are published by the headquarters office of the Association, 839 Seventeenth St., N.W., Washington 6, D. C.

Doehler Award—American Die Casting Institute

"For outstanding contributions to the advancement of the die casting industry and process," the Doehler Plaque and a $500 honorarium is awarded each year to the most eligible individual, group, technical society, or technical society committee.

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Nomination and supporting papers are received annually from January 1 to April 30, by the Award Committee, American Die Casting Institute, 366 Madison Ave., New York 17, N. Y.

Proceedings of the Asphalt Paving Technologists

Copies of Volume 18 of the *Proceedings of the Association of Asphalt Paving Technologists* for 1949 are now available. This covers the technical sessions of the association held at Detroit, Mich., on February 14 and 15, 1949.

Papers presented in the afternoon session, February 14 and morning and afternoon sessions of February 15 are published in this volume. These papers should be of considerable interest to those concerned in bituminous paving, covering such phases as the cause and treatment of slippery pavements; the effect of fillers on the durability of asphalt; paving mixture design; several methods of testing including the triaxial stability method and other papers of similar interest. Copies may be obtained from the Secretary-Treasurer, 1224 East Engineering Building, Ann Arbor, Mich., at a price of $4.

Schedule of A.S.T.M. Meetings

March 8	Philadelphia District	Philadelphia, Pa.
March 8	Joint S.A.E.-A.S.T.M. Technical Committee on Automotive Rubber	Detroit, Mich.
March 14	Committee D-7 on Wood	Chicago, Ill.
March 15–17	Committee D-13 on Textile Materials	New York, N. Y.
March 17	Committee C-18 on Natural Building Stones	Washington, D. C.
Wk. March 20 (Tentative)	Committee D-9 on Electrical Insulating Materials	Old Point Comfort, Va.
Wk. March 20 (Tentative)	Committee D-20 on Plastics	Old Point Comfort, Va.
March 21–22	Committee D-12 on Soaps and Other Detergents	New York, N. Y.
March 24	New York District	New York, N. Y.
March 27–28	Committee D-14 on Adhesives	(A.S.T.M. Headquarters)
March 28	St. Louis District	St. Louis, Mo.
March 29	Chicago District	Chicago, Ill.
April 10	New England District	Boston, Mass.
April 11–12	Committee B-1 on Wires for Electrical Conductors	(A.S.T.M. Headquarters)
April 21	Western New York-Ontario District	St. Catharines, Canada
April 27–28	Committee D-10 on Shipping Containers	Madison, Wis.
June 26–30	53RD ANNUAL MEETING AND 9TH EXHIBIT OF TESTING APPARATUS AND EQUIPMENT	Atlantic City, N. J.